

UNITED STATES AIR FORCE ARMSTRONG LABORATORY

AN EVALUATION OF ADVANCED MULTISENSORY DISPLAY CONCEPTS FOR USE IN FUTURE TACTICAL AIRCRAFT (U)

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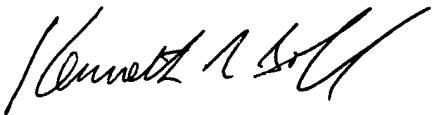
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FOR THE COMMANDER



KENNETH R. BOFF, Chief
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13. ABSTRACT (Maximum 200 words) Pilots from three NATO countries participated in simulated air combat scenarios in which they either flew a <i>conventional</i> cockpit, consisting of F-16/F-15-type cockpit displays, or a <i>virtually-augmented</i> cockpit, consisting of advanced head-down/head-up displays, helmet-mounted displays/trackers, 3-dimensional auditory displays, and haptic displays. Pilots flew simulated air intercept missions against a four-ship ground-attack group supported by two air-to-air adversary fighters. The pilot flying the principal cockpit was instructed to try to shoot down the ground-attack group and return to a pre-defined safe air space without being shot down by adversary aircraft. The degree to which pilot performance was differentially affected by the <i>conventional</i> versus <i>virtually-augmented</i> cockpit manipulation was assessed using objective and subjective measures including pilot-aircraft lethality/survivability, pilot workload, and pilot situation awareness. Results indicated a significant advantage for the virtually-augmented interface condition in the number of missions won, exchange ratio, mission length, and number of ground strikes. In addition, the performance improvements yielded by the virtually-augmented crew station were realized with enhanced situation awareness and a reduction in workload compared to the conventional crew station. Furthermore, post flight debrief questionnaires produced highly favorable subjective reports from pilots.				
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EXECUTIVE SUMMARY

This report describes a human performance evaluation of a prototype fighter aircraft cockpit design consisting of a variety of virtually-augmented, multisensory displays. This work was performed at the US Air Force Armstrong Laboratory's Synthesized Immersion Research Environment (SIRE) Facility at Wright-Patterson AFB, Ohio. Eighteen pilots from three NATO countries participated in simulated air combat scenarios in which they either flew a "conventional" cockpit consisting of standard F-15 types of cockpit displays, or a "virtually-augmented" cockpit consisting of a variety of novel visual and 3-D auditory displays. Pilots flew simulated air intercept missions versus two other pilots who operated enemy aircraft networked in the same virtual flight environment as the principal cockpit. A variety of preprogrammed aircraft models were also included in the scenario, including a patrol of four bombers and a "friendly" F-16 aircraft. The pilot flying the principal cockpit was instructed to try to shoot down all four bombers and return to a predefined safe air space without being shot down by the enemy aircraft protecting the bombers. The degree to which pilot performance was differentially affected by the "conventional" versus "virtually-augmented" cockpit manipulation was assessed using the following general classes of measures: pilot-aircraft system output, pilot workload, and pilot situation awareness measures. Results indicated a significant advantage for the virtually-augmented interface condition in the number of missions won, exchange ratio, mission length, and number of ground strikes. In addition, the performance improvements yielded by the virtually-augmented crew station were realized with enhanced situation awareness and a reduction in workload compared to the conventional crew station. Furthermore, post flight debrief questionnaires produced highly favorable subjective reports from pilots. The results are discussed in terms of their implications for the design of future airborne crew stations.

FOREWORD

The work described in this report was performed by members of the Human Interface Technology Branch, Human Engineering Division, Crew Systems Directorate, Armstrong Laboratory (AL/CFHP), Wright-Patterson Air Force Base, Ohio. The evaluation was conducted in the Synthesized Immersion Research Environment (SIRE) Facility. The authors would like to thank James Cunningham, Liem Lu, Dean Stautberg, Michael Poole, and David Hoskins for providing essential software and hardware support throughout all phases of this investigation; and the pilots who served as subjects for their enthusiastic participation and valued insights.

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1.0 INTRODUCTION

The purpose of this report is to describe a human performance evaluation conducted to assess the effect of two alternative fighter cockpit display designs on the performance of a simulated air combat task. The work was conducted at the US Air Force Armstrong Laboratory's Synthesized Immersion Research Environment (SIRE) Facility at Wright-Patterson Air Force Base, Ohio. The SIRE Facility is engaged in the development and evaluation of advanced crew station concepts for use in future USAF systems. These concepts, discussed in more detail below, are intended to lead to the production of functional interfaces that will enhance human performance by optimizing the extraction and comprehension of task-relevant information, as well as the execution of control activities. This work is intended to lead to more effective interface concepts for future USAF crew stations, and also supports the goals of the US/French Memorandum of Understanding Regarding the Cooperative Development and Evaluation of Super Cockpit Technologies.

As part of this effort, 18 pilots from three NATO countries (France, the United Kingdom, and the United States) participated as test subjects in a simulated air combat scenario. This simulation evaluation was designed to provide an objective basis for assessing the differential effectiveness of two fighter cockpit interface configurations in supporting the performance of a representative air combat task. The first crew station configuration, referred to as the "conventional" crew station, consisted of an array of standard F-15 and F-16 displays and controls.¹ The second crew station configuration, referred to as the "virtually-augmented" cockpit, consisted of a variety of interface concepts based largely on approaches to multisensory display design currently being explored in the area of "virtual reality" (e.g., National Research Council, 1995). These include *technical* innovations such as helmet-mounted displays and 3-D auditory localization systems, as well as *conceptual* innovations such as intuitive, multisensory specification of tactically relevant information. The overall goal of this design effort is to optimize pilot performance, workload, and situation awareness through more effective interface design. The accomplishment of this goal is being pursued by developing multisensory interface concepts that take advantage of the parallel information extraction capabilities of the various sensory modalities in such a way as to make the activities of perception and control more rapid and accurate.

1.1 An Approach to the Design of Advanced Crew Station Concepts

The evaluation described in this report was conducted as part of an ongoing effort to develop advanced interface concepts for future airborne crew stations. The SIRE Facility's approach to the design of advanced crew station concepts has two main characteristics: (1) continuous interaction between engineering and human factors research and development teams to promote effective systems design, and (2) behavioral research devoted to (a) exploratory evaluations of novel interface technologies, and (b) advanced evaluation of integrated interface technologies using operationally relevant tasks.

¹ A complete description of all displays and controls used in the evaluation is provide in Section 2.0 of this report.

Parallel engineering and human factors research and development.

The SIRE Facility possesses a multidisciplinary staff of individuals working toward the development of advanced, multisensory crew station concepts. Among the professional areas represented are electrical engineering, mechanical engineering, computer systems engineering, human factors engineering, and experimental psychology. In order to maximize the effectiveness of the interactions between these diverse groups, and to ensure that the products (i.e., crew station concepts) of the Facility are effective tools for enhancing human performance, the processes of engineering development and human factors analysis are very tightly coupled. Specifically, human factors analyses are conducted in conjunction with engineering development efforts to assess the "usability" of emerging systems and to explore potential applications. The results of these analyses are then fed back into the engineering design cycle to provide guidance for the next iteration of the interface concept. Therefore, rather than limiting the role of human factors to the performance of "proof of concept" evaluations at the end of a long cycle of engineering development, our approach is to promote continuous interaction between the two throughout the design process. In our view there is far less risk of producing a poorly designed crew station concept (from a human-machine performance perspective), and overlooking novel, effective applications of emerging interface technology, if human factors analyses are used as a design tool rather than simply as an evaluation method.

Fundamental and operational research.

The SIRE Facility's human factors research and development program operates on two parallel levels to support advanced interface development. On the first level, *fundamental* research is conducted to evaluate the potential utility of emerging display and control concepts. At this level of analysis, the questions that are addressed are concerned with whether or not an "immature" interface concept can be used to either: (1) convey useful information to a user in a meaningful and reliable fashion, or (2) afford control of a system in a reliable fashion.² The second, more operational, level of human factors analysis is primarily concerned with more advanced evaluations of relatively "mature" interface technologies as integrated into prototype crew station designs. This level of research is geared toward the evaluation of ensembles of interface concepts within the context of an operationally relevant setting, such as simulated air combat. An evaluation of this latter sort is the major focus of this report.

Within the last two years, SIRE research on fundamental aspects of emerging interface concepts has concentrated on the following areas: Combined visual-auditory display design (Cunningham, Nelson, Hettinger, Russell, & Haas, 1995; McKinley, D'Angelo, Haas, Perrott, Nelson, Hettinger, & Brickman, 1995), haptically-augmented control stick design (Brickman, Hettinger, Roe, Lu, Repperger, & Haas, 1996), direct vestibular display design (Cress, Hettinger, Cunningham, Riccio, McMillan, & Haas, 1996), brain-body actuated control of continuous and discrete tasks (Nelson, Hettinger, Cunningham, Roe, Lu, Haas, Dennis, Pick, Junker, & Berg, 1996), development of head motion prediction algorithms for helmet-mounted displays (Nelson, Hettinger, Haas, Russell, Warm, Dember, & Stoffregen, 1995), and development of behaviorally-

² The term "immature" is used in this context to describe interface concepts that are in a very early stage of technical development and that have not been widely investigated in terms of their effects on fundamental aspects of human perceptual-motor performance (e.g., brain-actuated control). The term "mature" is used to describe interface concepts whose technical development and related human performance knowledge base are relatively more advanced (e.g., helmet-mounted displays).

and physiologically-based algorithms for adaptive interface design (Brickman, Hettinger, Roe, Stautberg, Vidulich, Haas, & Shaw, 1995; Hettinger, Cress, Brickman, & Haas, 1996; Tripp, Hettinger, Haas, Nelson, & Wilson, 1995). The purpose of this work has been to explore the potential utility of novel approaches to the design of interfaces that are considered to be of potential benefit in supporting human performance of tactical aviation tasks. In general, the research questions that are addressed at this level of analysis relate to determining whether or not a particular emerging technology shows promise as a means of either conveying information to a user and/or facilitating system control.

Following an initial "screening" at the level of fundamental research, promising technologies are then integrated into functioning, prototype crew stations. These ensembles of interface technologies are then evaluated using simulated tasks that, to the greatest extent possible, replicate the conditions and constraints of the intended real world application of the system. Our most recent effort in this respect involved an evaluation of an earlier version of the virtually-augmented crew station concept investigated in the current effort (Haas, Hettinger, Nelson, & Shaw, 1995; Hettinger, Nelson, & Haas, 1994). This evaluation, summarized in Section 1.2.4, exemplifies a level of analysis designed to aid in the advanced development of interface concepts whose potential utility is already established. At this stage, research questions are related to investigating the effects of multiple interface concepts (both "in isolation" and in terms of their interactions with one another) on real-world measures of task performance.

1.2 Review of Prior Research

This section provides brief summaries of research efforts intended to evaluate the effectiveness of helmet-mounted and head-down visual displays, 3-D audio systems, and other novel display technologies for tactical aviation. Within recent years there has been an increasing emphasis placed on empirical investigations of the utility of virtual environment technology for use in future cockpits and other airborne crew stations. The majority of this work has concentrated on single modality displays, with primary emphasis placed on the visual modality. Recently, however, an increasing number of investigators have begun to examine the utility of other unimodal and multimodal display technologies.

While these summaries reflect the amount and type of effort that has been devoted to the test and evaluation of individual display concepts, there has been very little empirical work performed on human performance issues related to *integrated* cockpit display design. Research efforts conducted by Haas, Hettinger, Nelson, & Shaw (1995; reviewed below), as well as that performed as part of the current effort, are unique in terms of their evaluation of integrated crew station interface concepts.

1.2.1 Head-Down and Helmet-Mounted visual displays

The majority of work in crewstation display design has historically been focused on the visual modality. In recent years, the development of CRT- and LCD-based head-down displays, as well as the development of helmet-mounted displays (HMDs) has attracted a great deal of design attention. For instance, much recent work has been devoted to the use of color in aviation displays, as well as the use of pictorial format displays (Stokes, Wickens, & Kite, 1990; Reising & Emerson, 1982; Beringer, Allen, Kozak, & Young, 1993; Liggett, Reising, Solz, & Hartsock,

1996; Liggett, Reising, & Hartsock, 1992). It is generally hypothesized that the use of color and pictorial formats will present information to pilots in a more natural, intuitive manner, thereby enhancing overall performance.

Head-down displays.

Reising and Emerson (1982) discussed the potential of CRT-based cockpit displays coupled with advanced display processors. This early paper addressed an emerging capability for information display that was no longer limited to that which was possible with conventional electro-mechanical instruments. Furthermore, the authors advanced the hypothesis that the use of pictorial format displays would yield a more natural interface between pilot and aircraft than that afforded by traditional dial-type electro-mechanical displays.

More recently, Beringer, et al. (1993) examined the usefulness of the addition of color coding to a cockpit display of traffic information. Specifically, they evaluated the use of color coding to represent vertical trend information in a plan view horizontal situation display (HSD). They found that appropriate color coding yielded faster and more accurate threat classifications than a traditional numeric/symbolic HSD display, with no associated performance reduction in a concurrent flight control and navigation task.

Liggett, Reising, and Hartsock (1992) investigated the effects of a background attitude awareness indicator in a recovery-from-unusual-attitude flight task. The background attitude indicator was presented around the periphery of a head-down tactical information display. The authors investigated the effects of color shading (in which the background display became increasingly lighter in hue closer to the displayed horizon), color patterns (in which wedge-shaped solid color patterns slanted toward the displayed horizon were overlayed on the background display), and traditional pitch lines with numbers. These cues were tested separately, and in combination, and it was observed that initial control input time in the flight recovery task was fastest with the combination of color shading and color pattern than with the traditional pitch line indicator.

Liggett, Reising, Solz, and Hartsock (1996) evaluated a set of candidate electronic approach plates to determine which supported the best pilot performance when flying precision and non-precision approaches. In their evaluation, half of the subjects (pilots) flew precision approaches while the other half flew non-precision approaches. Four formats, varying in map orientation and color scheme, were used in each group: monochrome north-up, monochrome track-up, color north-up, and color track-up. While the authors reported no "practical" differences in performance observed with the four plate formats (although a statistically significant difference favoring the track-up orientation in the non-precision approaches was observed), they reported subjective ratings that were overwhelmingly in favor of the colorized approach plate format. In addition, subjective workload ratings were significantly higher for the monochrome displays as compared to the color displays.

Many other empirical investigations of head-down visual displays have been conducted in addition to those described above. For instance, Ellis, McGreevy, and Hitchcock (1987) have investigated perspective traffic displays for collision avoidance, and Mykityshyn and his colleagues have studied the development of electronic instrument approach displays (e.g., Mykityshyn & Hansman, 1991; Mykityshyn, Kuchar, & Hansman, 1994). It is generally the case, however, that

display concepts have been investigated in partial or total isolation from other relevant cockpit interfaces.

Research has been conducted to investigate the integration of head-down visual displays with various methods for selecting and/or interacting with information. For example, Liggett, Benson, Solz, and Reising (1995) compared three methods of designating targets on a tactical display including the use of touch screen controls, a standard target designator controller, and voice actuated control. Each of the three interfaces controlled the movement of a cursor on the tactical display. With the touch screen interface, subjects simply had to touch the target on the screen that they wished to designate, then press a button. The target designator controller was a commonly-used pressure-sensitive first order rate control similar. The voice actuated cursor controller required pilots to designate targets by reading the type and number next to a target on the display (e.g., "FIGHTER 1"). The experimental task used by Liggett and her colleagues required the subjects to designate four targets on each trial. The subjects were required to designate the targets as quickly as possible, without making errors. Results indicated that the touch screen controller produced the fastest target designation times. The results revealed that the touch screen controller was significantly faster than the target designator controller, which was in turn significantly faster than the voice controller. They also reported that errors of commission (i.e., designating the wrong target) were significantly lower with the voice controller and the touch screen controller (1.4 and 1.3 respectively) than with the target designator controller. Since the touch screen and the voice controllers were discrete controllers, the subject only designated the target they were interested in. However, the target designator controller required the subjects to move the cursor about the display and premature button presses produced an increased error rate. Although the touchscreen controller yielded the best performance in this experiment (faster times to complete the task, lower errors of commission) the authors point out that often during air combat maneuvering, the pilot must keep their hands on the throttle and stick to control the aircraft and weapons systems. Thus, the target designator controller and the voice controller were not discounted as possible interface devices on the basis of these empirical results. If anything, these results further emphasize the need to perform interface evaluations in an integrated, realistic setting.

Helmet-mounted displays.

Helmet-mounted displays (HMDs) offer a number of potential advantages for pilots of tactical aircraft. Chief among these is the ability to overlay synthetic, head-slaved visual information directly over the view of the out-of-the-cockpit visual environment. This capability enables direct visual access to critical information without requiring the pilot to make the additional head movements necessary to perceive stationary cockpit and head-up displays. Furthermore, such systems offer greater flexibility in allowing flight operations to continue day or night, in all weather conditions, with an increased margin of safety. These systems also afford increased safety during low level, terrain following, or nap-of-the-earth (NOE) flight. Finally, these systems offer significant tactical advantages when combined with helmet-mounted sight (HMS) weapons systems (Adam, 1994; Beal & Sweetman, 1994) by allowing the pilot to track and designate high off-boresight targets as much as 90 deg off the nose without any concomitant requirement for ownship maneuvering. The pilot simply looks at the target to establish weapons lock. When combined with high-off boresight missile capability (e.g., AIM 9X, see Dornheim & Hughes, 1995), HMD/S systems allow the pilot a greater probability of achieving a "first shot-first kill."

Much of the impetus driving the USAF commitment to HMD/S technology is the perceived threat emanating from the wide export market of Russian and Israeli high-off boresight missiles (AA-11 and Rafael Python 4 respectively) combined with helmet-mounted sights. For example, the AA-11 with helmet-mounted sight is being offered for export on MiG-29s, and as an upgrade for MiG-21s. MiG-29 aircraft exports alone represent approximately 750 aircraft flown by 17 different nations; 5500 MiG-21s are flown by 40 nations world wide (Dornheim & Hughes, 1995). The potential of this threat was evidenced in 1994 during exercises between the USAF and Germany in which German pilots flying MiG-29 fighters equipped with AA-11 ARCHER missiles and Russian built helmet-mounted sights achieved the all-important first shot against U.S. Air Force F-16s in 60% of engagements (Hughes, 1995).

There are several USAF programs engaged in investigating tactical implications of HMD/S systems (Beal & Sweetman, 1994; Dornheim, 1995a; Dornheim, 1995b). Two such programs are VISTA-SABER II. and VISTA-SABER N. These are a continuation of the VISTA-SABER work completed during the 1980s and are designed to assess current HMD/S systems and to delineate deficiencies with current HMDs to be remedied through requirements for future designs. The VISTA-SABER II. and VISTA-SABER N programs will equip two F-15Cs, one F-14A, and one F/A-18C with HMD/S systems and fly numerous 1 vs. 1, and 2 vs. 2 aerial engagements.

A second program is the Visually Coupled Acquisition and Targeting System (VCATS). This program is designed to achieve a producible HMS/S system that satisfies the requirements developed in the VISTA-SABER II. program. The VCATS program will terminate with the first flight of an F-15C equipped with the VCATS system. Following this first flight, the VCATS will be included in a Joint Navy/Air Force program called the First Shot Integrated Product Team.

First Shot is designed to evaluate a number of HMD/S candidates in "overall missile, helmet, and airframe system integration issues" (Dornheim, 1995b, p. 53). The results of the First Shot program are expected to feed into the Joint Helmet Mounted Cueing System (JHMCS). The JHMCS is the executor of a recently completed operational requirements document with the goal of deploying HMD/S systems into operational cockpits beginning around 2001 (Dornheim & Hughes, 1995; Dornheim, 1995a).

Among the important research issues to be addressed in the development of HMDs for tactical applications are those related to determining the amount and type of information to be displayed, its most effective presentation, and methods for optimizing the integration of information presented via the HMD with other visual and non-visual displays. While the VCATS, FIRST SHOT, and JHMCS programs are still in the developmental stages, the VISTA-SABER programs have produced several experimental evaluations of HMD/S technologies in the cockpit. Two such experiments are described below.

Arbak, King, Jauer, and Adam (1988) conducted an evaluation of a helmet-mounted sight and display (HMS/D) system in a simulated air-to-air combat situation. The HMS/D (a Kaiser Electronics Agile Eye) was used by F-15 pilot subjects to provide off boresight target acquisition information, to direct target detection and tracking with radar, and to assist in employing weapons. The HMS/D is intended to permit greater use of the large weapon and sensor coverage that exists outside of the HUD field-of-view (Olson, Arbak, & Jauer, 1991). The pilot can use head pointing to position sensors and missile seekers, which provides more rapid first shot capability. The effectiveness of the HMS/D was evaluated by comparing aspects of pilot performance (e.g., sensor

employment, weapons usage, and exchange ratios) across identical missions conducted with and without this virtually-augmented technology. The results of the evaluation indicated an initial slight decrease in performance effectiveness with the use of the HMS/D as pilots learned how to use the new display capability. This was followed by significant improvements in most aspects of measured performance by the end of the evaluation. For example, the exchange ratio observed with the use of the HMS/D nearly doubled over the course of testing while remaining constant in the non-HMS/D comparison condition. Pilot opinion data also strongly supported the use of the HMS/D for within-visual-range (WVR) operations.

As part of an evaluation of a Panoramic Cockpit Control and Display System (PCCADS) designed to enhance air-to-air combat mission effectiveness, Olson, Arbak, and Jauer (1991) investigated the effectiveness of an HMS/D system very similar to that used in the previous evaluation. The Kaiser Agile Eye system was once again used to assist pilots in designating targets in a simulated air-to-air combat scenario, and to provide head-slaved HUD type information on the helmet visor. The results of this evaluation corroborated those of Arbak et al. (1988) in that a significant (21%) increase in exchange ratio was observed in the HMS/D condition when compared to the standard, stationary HUD condition.

Results of this type are encouraging in that they demonstrate that pilots can quickly learn to employ a novel visual display technology and exploit its capabilities effectively. Current development efforts, as reflected in the present evaluation, are now concerned with the further exploration of effective display formats and the integration of helmet-mounted visual information with other types of novel display approaches, such as three-dimensional audio.

Developers increasingly consider HUDs and HMDs to be useful as primary flight reference displays, in addition to the tactical helmet mounted sight systems. Some novel work has begun to appear in this area. For example, Voulgaris, Metalis, & Mobley (1995) evaluated new attitude control symbology for use in HUDs or HMDs. They conducted an unusual attitude recovery task and compared performance between a novel "sky arc" display and a traditional pitch ladder display. Furthermore, the authors manipulated the workload associated with the task by controlling the "degree of difficulty" of the recovery; low, medium, or high. Performance measures included the time to complete the recovery, the correctness of the recovery procedure, as well as pilots' subjective impressions of the displays. The results indicated that the sky arc led to generally faster recoveries than did the standard display, as well as higher subjective preference ratings, despite the fact that pilots had literally thousands of hours more familiarity with the pitch ladder display. Furthermore, they reported that symbology confusion in terms of the correctness of the recoveries was far more prevalent with the pitch ladder symbology than the sky arc display.

DeVilbiss and Sipes (1995) also investigated arc segmented attitude symbology on HMDs using an unusual attitude recovery task. They caution that any symbology for the flight reference displays in an HMD must adequately take into consideration the tactical symbology already present on the display. In addition, they point out that some "off axis" orientation information may be helpful. Their findings revealed that when orientation information was presented, pilots were able to initiate unusual attitude recoveries at least 500 ms faster than when no orientation symbology was presented. That is, the off axis HMD orientation symbology allowed pilots to initiate the recovery before they reoriented themselves to the primary flight instruments.

Weinstein, Gillingham and Ercoline (1994) conducted empirical work aimed at the production of a military standard Head Up Display to be used as a primary flight reference during

instrument conditions. They conducted a series of 5 experiments that evaluated various symbology designs. The experimental tasks employed during these studies included recovery from unusual attitudes, Instrument Landing System (ILS) approaches, and precision instrument flight tasks. After summarizing a number of findings, they produced a set of guidelines to be included in the HUD standard. The HUD standard was then subjected to both simulator and actual flight tests. The HUD standard was compared to the head down instruments in the F-16A aircraft in simulations of recovery from unusual attitudes, precision flight control tasks and an ILS approach task. They report that the HUD standard yielded performance equal to the head down displays in both the precision flight task and the recovery from unusual attitude tasks, and better performance than the HDDs for the ILS approach task. Following the completion of the flight test, the HUD standard was certified for instrument flight and included in the MIL STD 1787A *Aircraft Display Symbology*.

1.2.2 3-D audio displays

Within the last decade, headphone-based auditory display technologies have been developed that are capable of generating sound sources that can be localized in an apparent three-dimensional space centered about the user's head (e.g., Ericson, McKinley, Kibbe, & Francis, 1994; Foster, 1988; Gehring, 1990). The potential utility of this display technology for improving the performance of tactical aviation tasks has been recognized for some time (e.g., Calhoun, Valencia, & Furness, 1987; Haas, 1992), and research efforts are underway in a number of locations to develop 3-D audio display applications for the cockpit. Acoustic signals, particularly when localizable in three-dimensional space, have many useful features that can be exploited for effective display design. For instance, acoustic signals can be heard simultaneously in three dimensions, they tend to produce alerting and orienting responses (i.e., they "direct the eyes"), and they can be detected more quickly than visual signals (Mowbray & Gebhard, 1961; Patterson, 1982; Wenzel, 1992). The auditory modality is also particularly adept at the detection of temporal information, and humans are very sensitive to changes in an acoustic signal over time (Kubovy, 1981; Mowbray & Gebhard, 1961).

Researchers are beginning to examine the utility of 3-D audio displays for use in applied aviation settings. For example, Ericson et al. (1994) performed laboratory and in-flight experiments to evaluate 3-D audio display technology for cockpit applications. As part of their work, they developed a 3-D audio display generator which digitally encodes naturally occurring direction information onto any audio signal and presents the binaural sound over headphones. As with most other 3-D audio devices, the acoustic image is stabilized with respect to the head by use of a head-tracking device. Head stabilized acoustic images can thus provide information about the location of environmental sound sources in a manner which is invariant with respect to head position. In their laboratory evaluation, Ericson and his colleagues used the 3-D audio display generator to spatially separate competing speech messages in an attempt to improve the intelligibility of each message. Their results indicated that the use of the 3-D audio display resulted in a 25 percent improvement in speech intelligibility for spatially separated speech at high ambient noise levels (115 dB SPL). During in-flight evaluations, test pilots reported that spatial separation of speech communication provided a noticeable improvement in intelligibility.

Localized acoustic displays have also been evaluated as potential aids for tactical, visual target acquisition tasks. Cunningham, Nelson, Hettinger, Russell, & Haas (1995) recorded head position data and target detection latency and accuracy to assess the effects of spatially separated

acoustic information on target detection performance. Subjects in this study visually scanned a large field-of-regard dome display in an attempt to detect the rapid approach of a simulated SU-27 fighter aircraft from a randomly determined location. A variety of combinations of visual display conditions (e.g., full field-of-view, limited field-of-view, helmet-mounted display, etc.) were crossed with a variety of auditory display conditions (e.g., auditory information localized with respect to target location, non-localized or "warning tone" auditory information, no auditory information, etc.). Graphical representations of subjects' head motion activity revealed strong qualitative differences in search strategies between conditions in which localized auditory information was and was not presented. The presence of localized auditory information made it possible for subjects to restrict their head motions to a comparatively small sector of the visual array. In addition, head position data were used to calculate two quantitative metrics of head motion: Total angular displacement of the head and average head velocity. Analyses of these data indicated that localized auditory information was associated with significant reductions in both angular head displacement and head velocity. Other measures of performance such as percentage of targets correctly detected, apparent visual distance of detected targets, and mean overall workload also showed consistent significant advantages for the use of localized sound. Ericson et al. (1994) also observed improved visual target detection capability with the use of a 3-D audio display.

Further developments in this technology are needed to enhance the localization capability of 3-D audio systems, perhaps through the development of individualized head-related transfer functions (HRTFs) for each user. The HRTF is an important physiological parameter, which determines critical spectral shaping characteristics of sound that are largely unique to each individual by taking into account the size and shape of the head and the pinnae (external ear) - two critical determiners of auditory localization behavior. In addition, while current displays are capable of providing salient cues with respect to the azimuth and elevation locations of acoustic signals, the presentation of veridical auditory depth cues is still lacking. Finally, the ability of the human to effectively attend to various types of localized information as a function of the characteristics of the sound sources (e.g., frequency, band-limitation characteristics, etc.) must also be examined. In the current evaluation we chose to evaluate a 3-D audio display that provided information about ground proximity, and the location and nature of enemy threats in a simulated air combat setting. In a prior investigation (Haas, Hettinger, Nelson, & Shaw, 1995) we obtained results that were suggestive of performance advantages with the use of such a display. This evaluation is described in the following section.

1.2.3 Multisensory displays

A recent trend in interface design reflects an interest on the part of developers to take advantage of a perceived performance advantage in utilizing the normal human capacity to perceive information in a multisensory fashion. With advancing developments in display technologies geared toward the visual, haptic, and auditory modalities, the possibility of incorporating advanced multisensory displays in tactical aircraft is becoming a very practical possibility.

Until the 1990s, integrated multisensory display technologies for the cockpit received very limited attention in the research and development community. For instance, in his discussion of the "supercockpit," Furness (1986) was one of the first to introduce the concept. Since that time there has been steadily increasing interest in applying multisensory display technology developed under the moniker of "virtual reality" to cockpit design. Haas (1992) and Haas and Hettinger (1993)

have also commented on the potential advantages of multisensory displays for tactical crewstations.

Selcon, Taylor, and Shadrake (1992) investigated the requirements and potential benefits afforded by multisensory cockpit warning systems. They evaluated subjects' ability to respond to threat warnings presented either visually, auditorally, or combined visual-auditory presentation. They measured subjects' reaction time to the threat warning, their ability to classify the criticality of the threat, and situation awareness as measured by the Situation Awareness Rating Technique (SART). Results indicated that subjects' reaction times were significantly faster with the combined visual-auditory presentation. In addition, they found that responses to the visual-only warnings were significantly faster than under those observed with the auditory-only displays. However, they reported no differences between conditions for error rate or threat classification performance. The SART ratings indicated that workload associated with the visual-only condition was significantly greater than that for either the auditory-only or combined visual-auditory conditions. The visual-auditory condition also yielded significantly higher ratings on the "understanding" subscale than either of the two unimodal displays, reflecting the greater ease with which information could be extracted under the multisensory condition.

Hopper (1992) discusses panoramic cockpit displays and describes three versions of the future of tactical crewstation design. The first, PCCADS 2000 was designed to make use of current technology. This display concept includes a 100 square inch primary display flanked by a six inch display on either side. In simulation testing, this display concept produced a 28% increase in exchange ratio over a simulated F-15E with traditional instruments. When an HMD was added, the exchange ratio was increased by 45% over the traditionally equipped crewstation. The second concept, for the year 2000 includes either a 2000 square centimeter or a 200 square inch head down color display. The third concept crewstation, for introduction around 2020 incorporates a completely encapsulated crewstation. That is, the pilot will have no direct view of the outside world. The concept represents a radical departure from traditional crewstation designs and will include visual, audio, and haptic information displays.

Ineson (1994) recently reported an initiative to develop the Advanced Panoramic Helmet Interface Demonstrator System (APHID) in the United Kingdom. The APHID system is proposed to include a Helmet Mounted Display, 3-Dimensional sound cueing, and finger, head, and eye tracking capabilities.

1.2.4 An initial evaluation of integrated virtually-augmented crew station displays

An earlier evaluation was conducted at the Armstrong Laboratory's Fusion Interfaces for Tactical Environments (FITE) Laboratory to investigate the effects of advanced multisensory interfaces on the performance of a simulated air combat task (Haas, Hettinger, Nelson, & Shaw, 1995; Hettinger, Nelson, & Haas, 1994). This investigation sought to empirically examine performance differences between an advanced, "virtually-augmented" tactical crew station and a more "conventional" tactical crew station comprised primarily of F-15 types of displays and controls. The evaluation required experienced USAF fighter pilots to intercept and destroy four enemy bombers using one of the two possible crew station configurations (virtually-augmented or conventional) on each mission. The bombers were defended by two piloted enemy fighters. Thus, three pilots participated simultaneously during the performance of each mission. Each of the

piloted aircraft was equipped with similar ordnance including IR and AMRAAM guided missiles and a 20 mm cannon.

The primary cockpit used to support both crew station configurations consisted of an F-16 aluminum shell, six in-cockpit liquid crystal displays (LCDs), a Head-Up Display (HUD) projected on a screen in front of the pilot, F-16 C throttle and sidestick controller, audio display system, and a helmet-mounted display (used in conjunction with the virtually-augmented crew station only). The simulator was housed in an 8' x 8' x 8' cubic projection room. The out-the-window visual display was presented on the cube by six Limelight monochrome projectors. The entire simulation system was run on a network of 24 80-486 33 MHz microcomputers.

Each mission was flown with the primary cockpit in one of two possible configurations. The conventional crew station included displays and controls similar to many currently operational tactical aircraft (e.g., F-15, F-16). This crew station included an Air-to-Air Radar Display, a Radar Warning Receiver, Airspeed Indicator, Attitude Indicator, Altimeter, Systems Stores Display, Horizontal Situation Display, and a variety of audio signals. The virtually-augmented crew station included a large pictorial format color display presenting a schematic representation of the out-the-cockpit terrain (providing altitude and forward speed information). A radar display employing novel approaches to symbology and color coding was superimposed over this display. In addition, localized audio cueing, a Ground Collision Avoidance System (GCAS), and an HMD that allowed the pilots to establish radar locks on enemy aircraft outside of the plane of maneuvering of their own aircraft were provided. To the extent possible, both crew station configurations were provided with the same *types* and *amount* of information, but presented in vastly different formats. The one notable exception to this was the use of GCAS in the virtually-augmented condition - a feature not currently employed in US fighter aircraft and therefore not included in the conventional crew station in this evaluation.

Four experienced USAF fighter pilots flew a total of 12 simulated intercept missions each; six missions were flown using the conventional crew station design and six using the virtually-augmented design. Each pilot also flew 24 missions in command of an enemy fighter aircraft, using a simplified auxiliary control station. The mission required the primary cockpit to successfully intercept and destroy all four of the computer controlled enemy bombers and to egress to safe airspace without being shot down by the enemy fighters. Trials were terminated if the primary cockpit accomplished the mission, was shot down, ran out of fuel, or forfeited the mission via voice call for any other reason.

The results of this evaluation revealed few meaningful differences between the two crew station designs across a wide range of air-to-air combat performance measures. Analyses of variance revealed no statistically significant differences between the two cockpit configurations in either the number of enemy bombers killed, or in the number of enemy fighters destroyed. Similarly, a questionnaire designed to assess pilots' situation awareness (SA) during the performance of the mission revealed no statistically significant differences between the two crew station designs. However, there were two areas of substantial difference between the two designs that were considered to be directly linked to pilot SA: (1) The number of accidental ground strikes, and (2) the number of fratricidal incidents associated with the use of each crew station design. Pilots flying the virtually-augmented crew station did not suffer any ground strikes throughout the entire evaluation. In contrast, pilots flying the conventional crew station experienced ground strikes on 12.5% of all missions flown. Similarly, when using the virtually-augmented crew

station, pilots did not commit any fratricidal attacks versus a 12.5% fratricide rate observed with the use of the conventional crew station.

Although there were no statistically significant combat outcome differences between the two interface conditions, it is important to consider the experience that the pilots had with these crew station configurations. Each of the pilots had literally hundreds of hours flying aircraft with displays quite similar to those included in the conventional crew station. By comparison, the pilots had very limited training (approximately 4 hours each) on the use of the novel displays used in the virtually-augmented condition. Given these vast differences in training, it is possible that a substantial increase in mission effectiveness would be observed with increased training in the virtually-augmented crew station. In addition, the presence of large performance differences in the number of crashes and fratricides also suggests an advantage for the virtually-augmented interface.

The evaluation to be described in the current report was undertaken to further investigate the performance effects of the virtually-augmented crew station described above. Enhancements were made to the on-line performance measurement capabilities of the FITE Laboratory which were expected to provide greater precision in the assessment. In addition, on the basis of the initial results described above, enhancements were made to the virtually-augmented crew station's visual and auditory displays. These improvements were expected to provide a greater performance advantage over the conventional crew station.

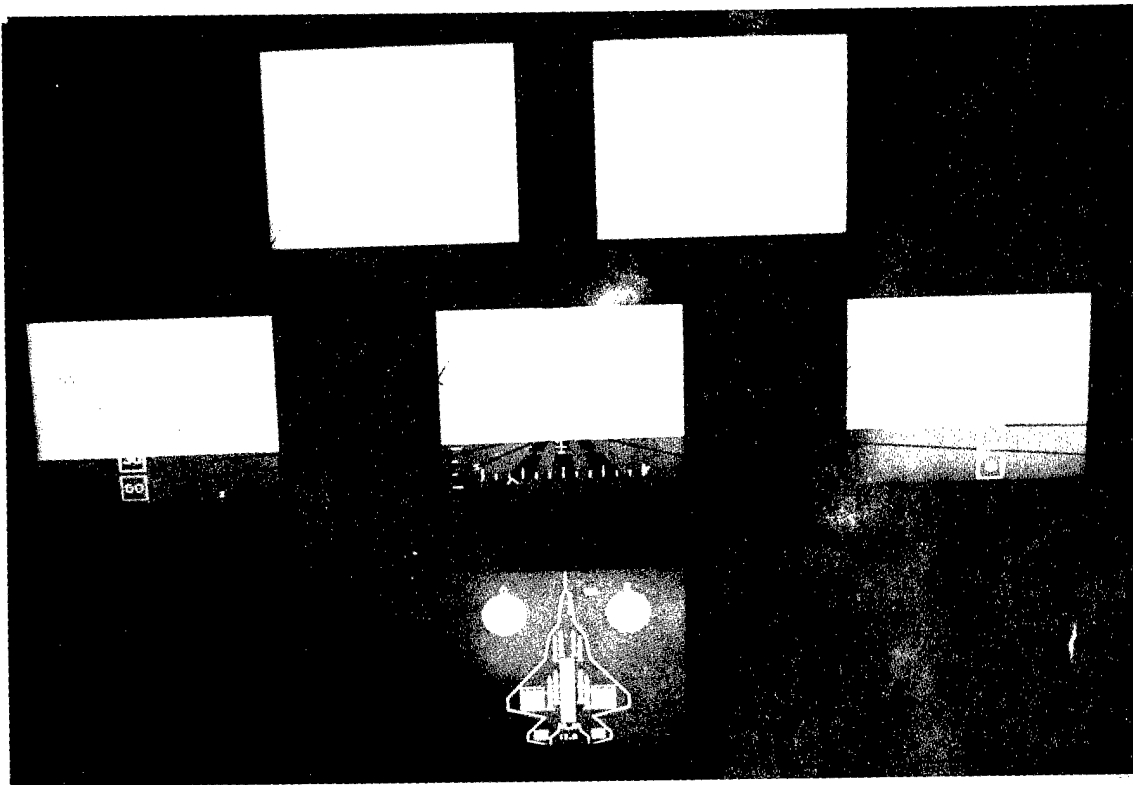
2.0 CREW STATION DESCRIPTION

2.1 Virtually-Augmented Crew Station

The virtually-augmented crew station condition consisted of a modified HDD configuration, a "see-through" HMD, a localized audio display, and a Ground Collision Avoidance System (GCAS). The modified HDD consisted of a pseudo large-screen display, generated by coupling the six in-cockpit LCD displays (see Color Plate 1 and Figure 1). The large screen display provided pilots with a simulated out-the-window view including a horizon line, ground (light tan), sky (light blue), and moving ground textures (tan blocks). The simulated OTW display also incorporated several powerful monocular depth cues. First, ground textures were drawn in linear perspective, indicating the distance from the aircraft to the horizon. Second, ground textures were presented in streaming perspective when the aircraft was in motion. That is, the ground textures appeared to move from the horizon line (far) toward the aircraft (near) at a rate that was proportional to the aircraft's ground speed. The ground textures also moved in relation to the bank of the aircraft in a turn. For instance, when banked with the left wing down, the texture units moved from left to right to enhance the visual impression of the turn. Third, the apparent size of the ground texture was inversely related to the aircraft's altitude. Thus, increases in altitude caused the ground texture to appear smaller and more distant. Altitudes above 10,000 ft, however, were not accompanied by decreases in ground texture size. The single LCD located at the bottom of the modified HDD was referred to as the System Status Indicator (SSI) display, and it was used to provide pilots with mission-relevant information including weapons mode and counts, chaff and flare counts, speed brake information, and fuel quantity information.

A Kaiser Electronics Agile Eye (monocular) HMD was equipped with a transparent visor that allowed an auxiliary HUD to be presented to the pilot whenever his line of sight was aimed away from either the HDD or the HUD. In other words, the HUD in the HMD would "pop-up" whenever the pilot was not looking straight ahead or down at the HDDs. The format of the HMD's HUD was almost identical to the aircraft HUD, with the addition of a "hot box" targeting feature and several radar mode indicators.

The GCAS was used to warn pilots when immediate action was required to avoid collision with the ground (see Color Plate 2). The GCAS utilized information about the aircraft's current height above the ground, descent rate, dive angle, airspeed, and bank angle to compute an alert altitude. Based on these calculations, a GCAS alert was issued to allow the pilot a minimum of 4-sec to begin a 4 g recovery from a dangerous flight path. The GCAS alert was displayed on all visual and auditory displays in the virtually-augmented crew station. At the initiation of the GCAS alert all of the HDDs flashed red, and an auditory warning signal - a "doorbell" sound effect localized so that it appeared to emanate from the direction of the ground - was presented through the headphones. Simultaneously, a large arrow was superimposed on the HUD, HMD, and center LCD of the HDD to indicate the vertical "up" direction as an aid in recovering the aircraft to an upright attitude. The vertical "up" arrow also included a pair of brackets that moved together at a rate proportional to the aircraft's closure rate with the ground. The brackets were displayed so as to meet at the center of the "up" arrow upon ground impact. After the initial four sec of the GCAS alert, the HDD ceased to flash red and the "doorbell" audio warning signal was replaced with a "siren" sound effect that increased in both pitch and volume with decreasing height above the ground. This sound effect was also localized to appear to emanate from the direction of the



Color Plate 1. Virtually-Augmented Crew Station Displays

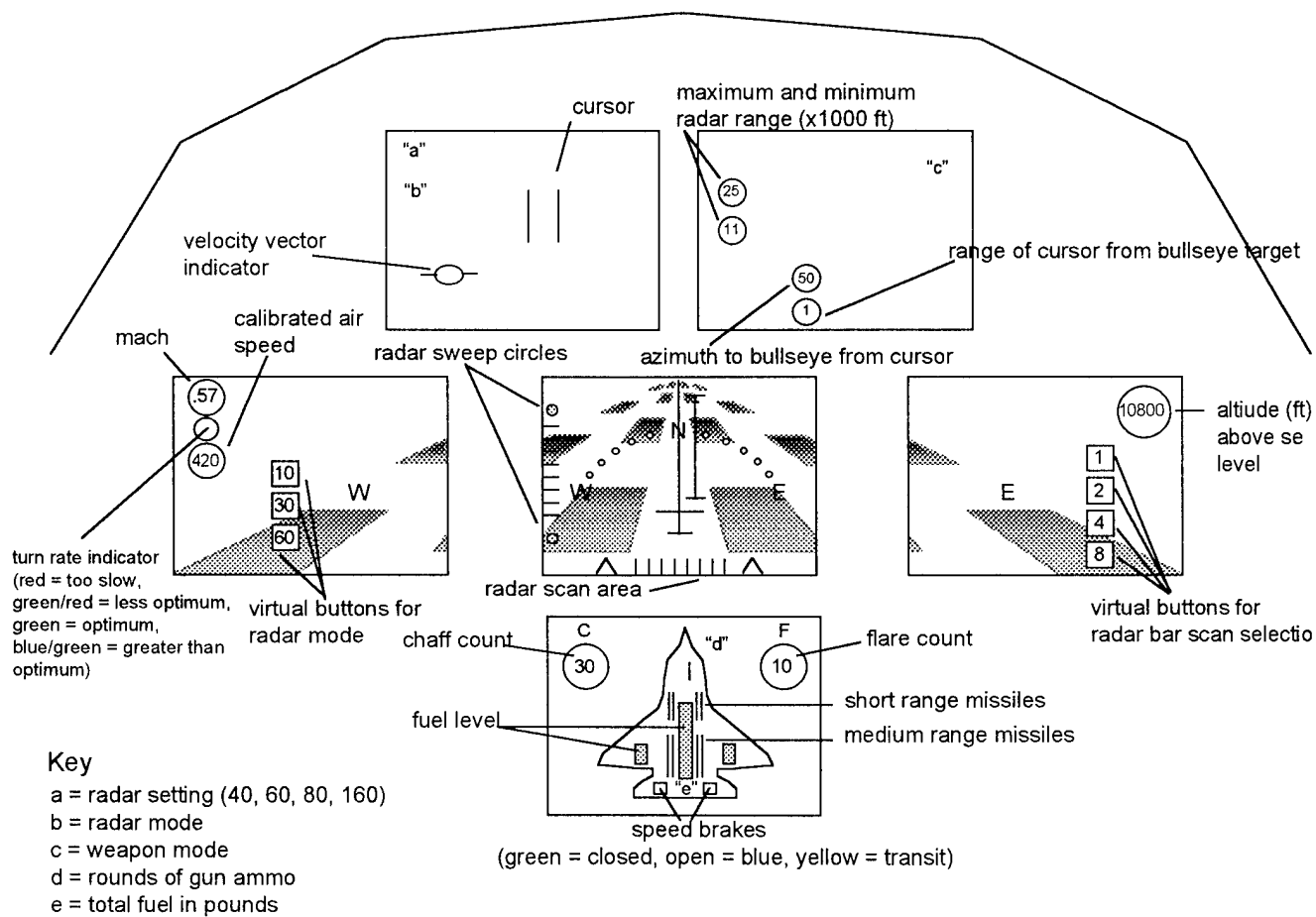
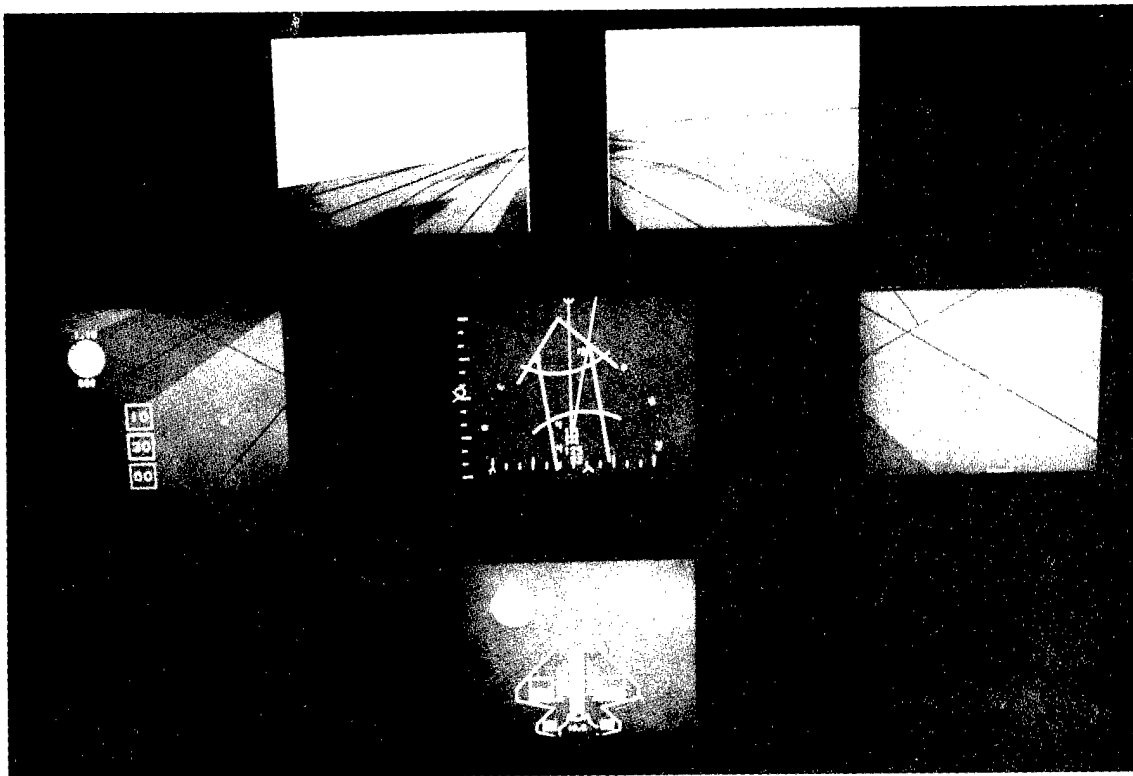


Figure 1. Virtually-Augmented Crew Station Schematic



Color Plate 2. Ground Collision Avoidance System

ground. All GCAS warning signals and displays were terminated as soon as the alert condition criteria were no longer met.

2.1.1 Virtual auditory display

Localized auditory information, presented to pilots via headphones mounted inside the flight helmet, was also included in the virtually-augmented crew station. This auditory display featured an array of meaningful sound effects that appeared to originate from external sound sources in three dimensional space. The generation of the sound effects was controlled by one 486 - 66 MHz microcomputer in conjunction with Sound Operating System software and two Sound Blaster audio cards. The left and right channels of one of the sound cards were used, while only the left channel of the other sound card was used. Each of these three channels was assigned three to five different sound effects. However, each channel was restricted to producing only one sound effect at a time. Thus, it was necessary to prioritize the sound effects for each channel. Table 1 lists the sound effects - from highest to lowest priority - associated with each channel. If two sound effects were activated by one channel, the sound effect of highest priority was played over the headphones.

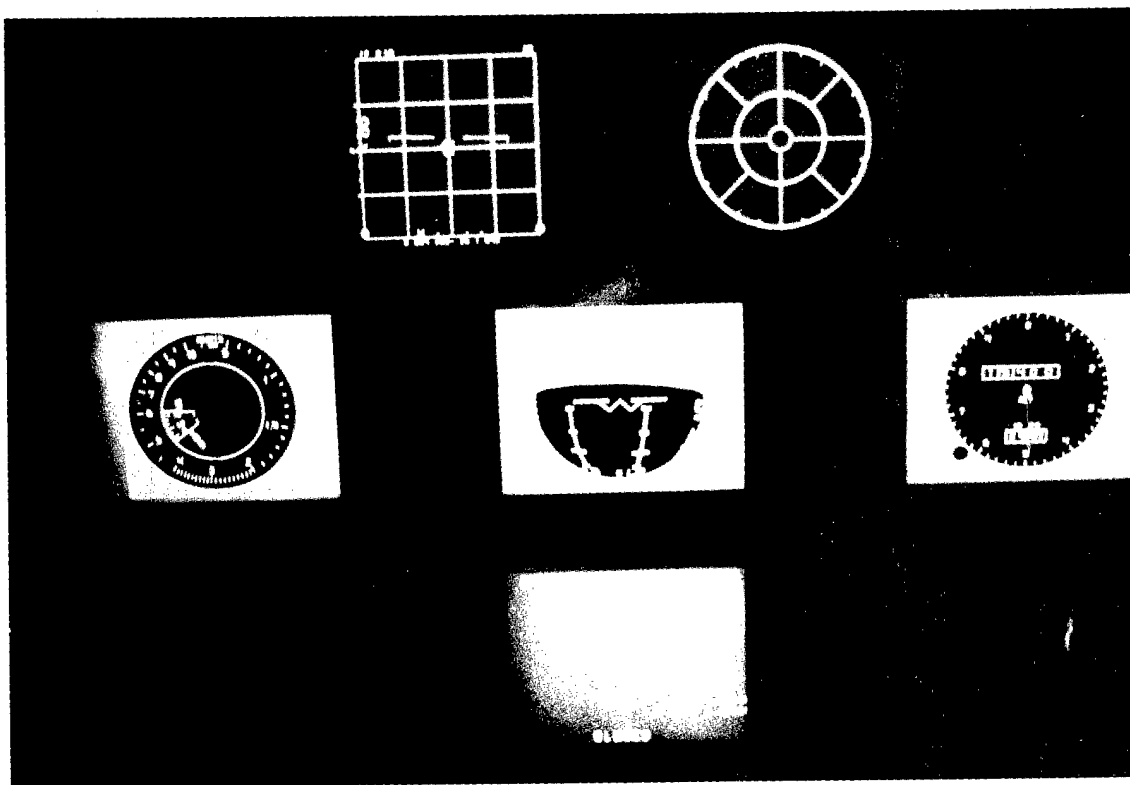
Table 1
Prioritized Listing of Sound Effects Presented in the Cockpit

SOUND COMPUTER		
Left Channel Card 1	Right Channel Card 1	Left Channel Card 2
Guns	Gcas_1	RWR detection beeps
Missile whoosh	Gcas_2	Missile RWR
Missile lock tone	Joker fuel	Fighter RWR
Missile growl_high		Bomber RWR
Missile growl_low		

All sound effects produced by the left channel of card 1, as well as the "joker fuel" sound effect produced by the right channel of card 1, were non-localized. In contrast, the GCAS sound effects produced over the right channel of card 1 and all sound effects produced over the left channel of card 2 were localized with respect to their apparent sources of origination in the simulated environment. Localization of sound effects was controlled by a Convolvotron, a commercially available localized audio display system.

2.2 Conventional Crew Station

The conventional crew station condition consisted of an array of standard visual and auditory displays usually provided in an F-15 fighter to conduct air defense missions. The manner in which the conventional crew station's visual displays were organized across the available LCDs in the primary cockpit is illustrated in Color Plate 3 and Figure 2. The displays that were



Color Plate 3. Conventional Crew Station Displays

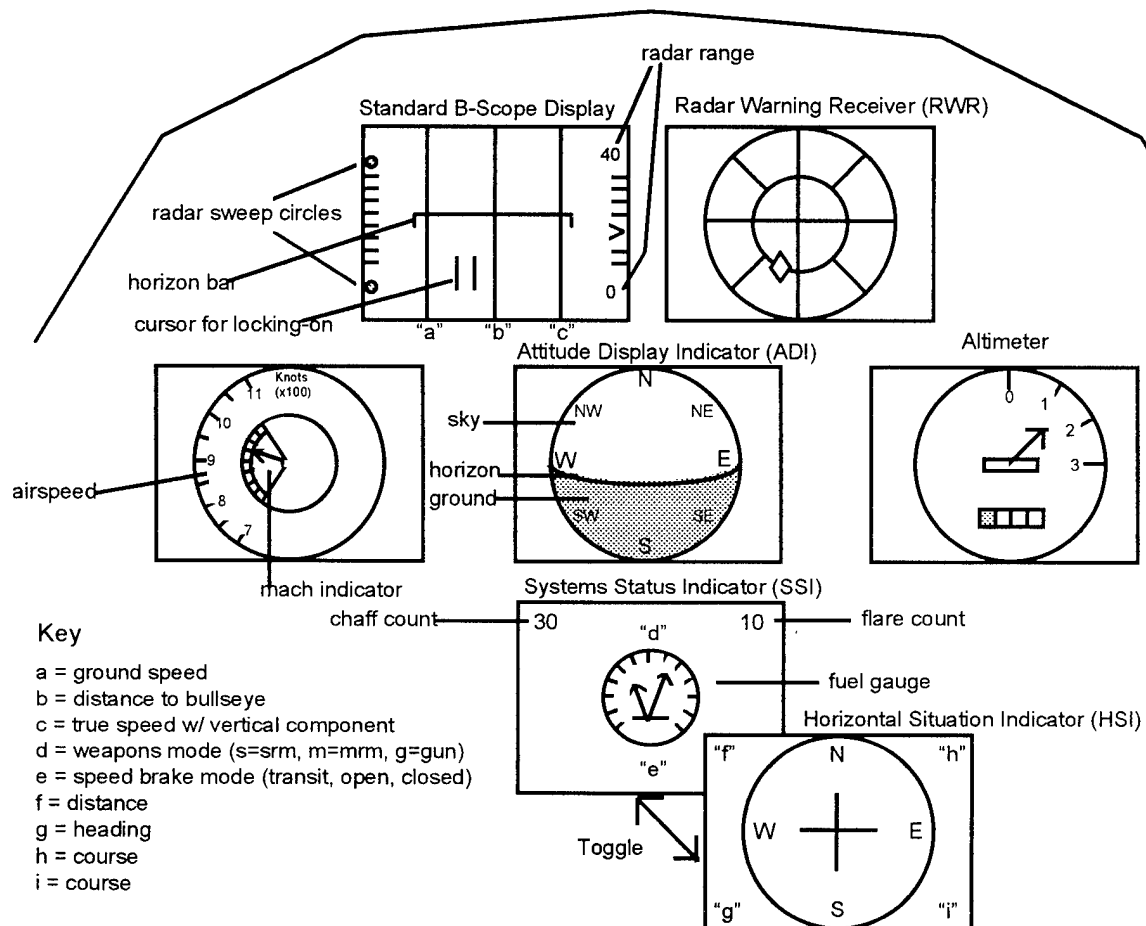


Figure 2. Conventional Crew Station Schematic.

provided included (from left to right and top to bottom): an Air-to-Air B-scope display, a Radar Warning Receiver (RWR) display, an Airspeed Indicator, an Attitude Display Indicator (ADI), an Altimeter, and a dual-function display that consisted of a Systems Status Indicator (SSI) and a Horizontal Situation Indicator (HSI). In the case of the dual-function display, pilots were able to manually toggle between the SSI and HSI displays.

The B-Scope display, RWR display, Airspeed Indicator, Altimeter, ADI, and HSI all employed instrument designs that closely replicated traditional fighter cockpit instrumentation. The SSI, however, was designed as a composite display in order to maximize the use of the HDD's limited display area. The SSI provided pilots with several sources of information that are considered relevant to air combat missions - it consisted of a weapons mode and count indicator, chaff and flare count indicator, a fuel gauge, and a speed brake mode indicator. Although the SSI is not a standard fighter cockpit display, it employed traditional symbology to display its information.

2.2.1 Conventional auditory display

All trials were accompanied by an array of meaningful sound effects that were presented to pilots via headphones mounted inside the flight helmet. The generation of the sound effects was controlled by one 486 - 66 MHz microcomputer in conjunction with Sound Operating System software and one Sound Blaster audio card. Only the left channel of the sound card was used. This channel was assigned five different sound effects, however, the channel was restricted to producing only one sound effect at a time. Thus, it was necessary to prioritize the sound effects for the channel. Table 2 lists the sound effects - from highest to lowest priority - associated with the channel. If two sound effects were activated, the sound effect of highest priority was played over the headphones. All of the sound effects produced by the left channel of the audio card were non-localized, and controlled by the Convolvotron system.

Table 2
Prioritized Listing of Sound Effects Presented in the Cockpit

SOUND COMPUTER

Left Channel of the Audio Card

Guns
Missile whoosh
Missile lock tone
Missile growl_high
Missile growl_low

3.0 FACILITY DESCRIPTION

3.1 FITE Facility Description

The current evaluation was conducted in the FITE Laboratory, contained within the SIRE Facility. A block diagram of the FITE Laboratory is presented in Color Plate 4. The simulator used for the primary cockpit was fixed-base and consisted of an aluminum F-16 enclosure, 6 head-down liquid crystal displays (LCDs), an intercom system, an F-16 C throttle, and a F-16 C sidestick controller. The cockpit was housed in a cubic projection room that measured 8' x 8' x 8'. All visual and auditory displays were controlled by a network of 23 80486 microcomputers. The displays used in this evaluation included an out-the-window display (OTW), several head-down displays (HDDs), a head-up display (HUD), a helmet-mounted display (HMD), and localized and non-localized auditory displays.

The OTW display, which included buildings, clouds, ground patterns, and other aircraft, was projected onto the surface of the cubic projection room by six, black and white Limelight projectors, each of which was driven by an 80486 microcomputer. The OTW display was projected onto the left, right and front walls, as well as the ceiling of the projection room. This arrangement provided pilots with a 240 deg (horizontal) x 120 deg (vertical) field-of-view (FOV). The horizontal FOV was +/- 120 deg from the design eye, whereas the vertical FOV ranged from 30 deg below to 90 deg above the design eye.

The HDDs, which were located on the instrument panel of the cockpit, consisted of six, rectangular, color LCDs. All of the LCDs measured 9 cm x 12 cm, and had 1280 x 1024 pixel resolution. Each LCD was controlled by a 80486 microcomputer, with an update rate of 6 Hz.

The HUD (depicted in Figure 3) was projected onto the center of the front projection screen, directly in front of the cockpit, and was generated using a 80486 microcomputer containing a high resolution graphics card in combination with a green monochrome Limelight projector. It was focused at infinity, and occupied a 20 deg x 20 deg FOV. In both the conventional and virtually-augmented crew station conditions, the HUD was used to provide pilots with information regarding the status of numerous flight parameters, as well as information regarding the navigation, radar, and weapons systems. The layout of the HUD used in this evaluation closely approximated the "declutter mode" format employed in contemporary fighter HUDs.

Pilots participating in this evaluation flew the primary cockpit in each of two possible configurations: (1) a "virtually-augmented" crew station configuration in which a variety of advanced, integrated interface concepts were employed, and (2) a "conventional" crew station configuration in which a variety of standard F-15 style displays were employed.

3.2 Threat Crew Stations

The aggressor threat stations involved in the scenario were comprised of two aircraft simulation stations, each consisting of a flight control stick, throttle, intercom, and 17 in. high-resolution monitor (see Color Plate 5). Each station was capable of displaying two different visual interface modes. The first mode closely resembled the HUD display in the principal cockpit, and was used to provide the aggressor pilots with information regarding the status of numerous flight parameters, as well as navigation, radar, and weapons systems information (see Figure 4). The



Color Plate 4. Primary Cockpit Crew Station

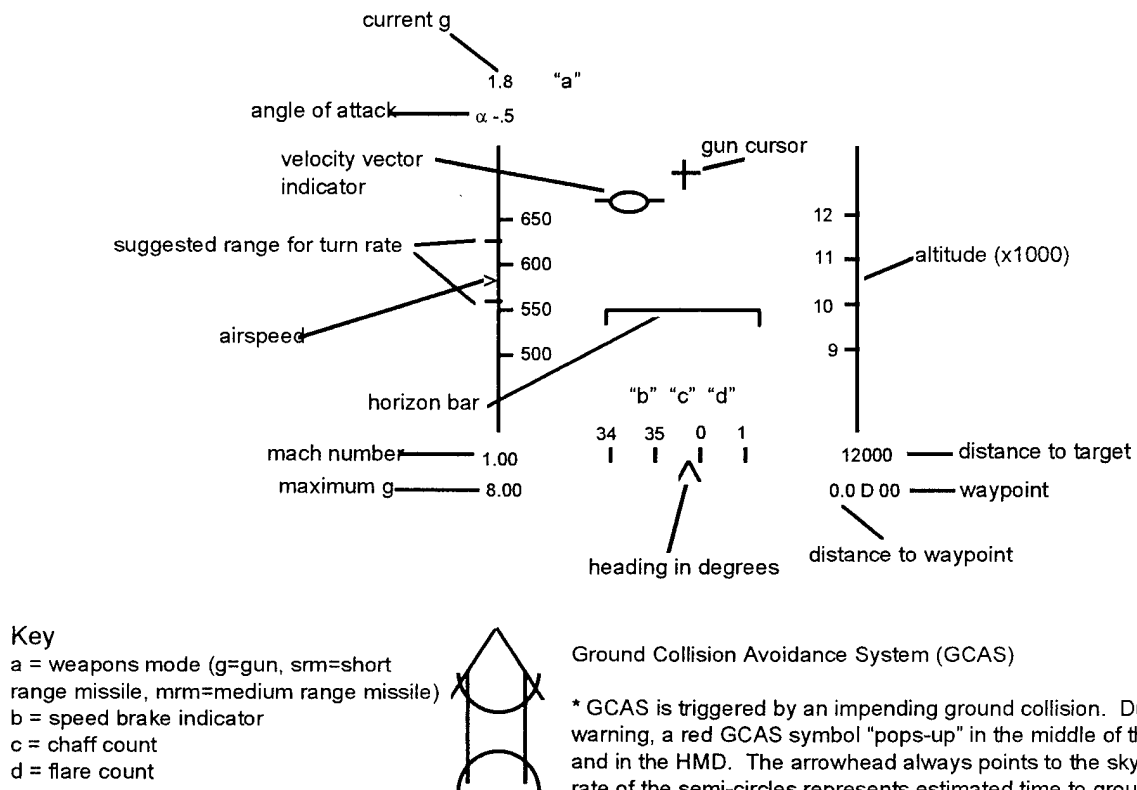


Figure 3. Head - Up Display Diagram.



Color Plate 5. Pilot Operating Threat Station

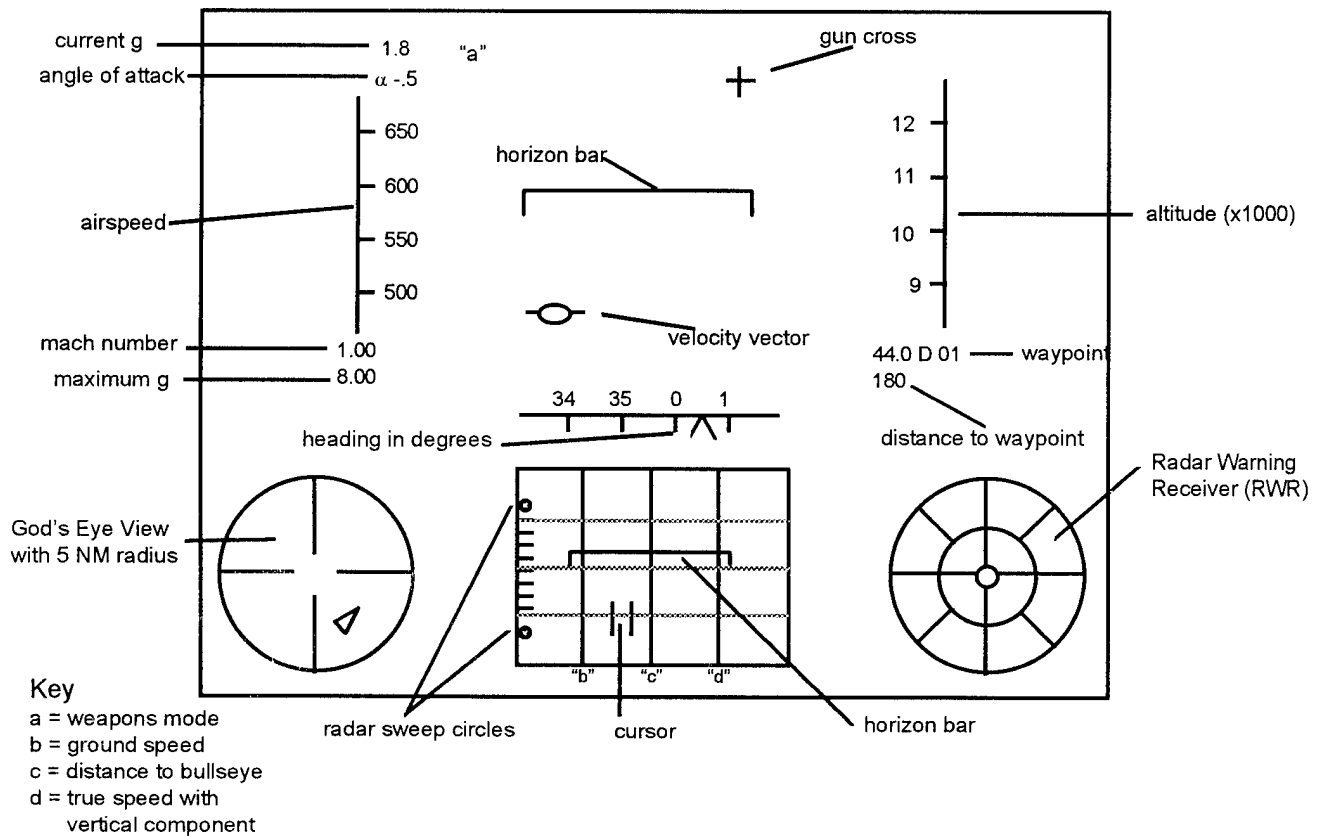


Figure 4. Threat Station HUD Display.

second mode, or the cone-display, consisted of a 2-dimensional planar depiction of the pilot's outside view (see Figure 5.). The bottom of the cone display represented the outline of the cockpit canopy and the aircraft surfaces that would normally restrict the pilot's outside visibility. The center of the outline illustrated the fighter's instrument panel with a simplified HUD in the center. The W-shaped symbol on the HUD is a "waterline" symbol commonly used in aircraft attitude indicators to represent the aircraft. The center of the W represents the aircraft's longitudinal axis, around which the fighter rotates in a rolling maneuver at zero angle-of-attack and zero sideslip. The rest of the aircraft, canopy rail, wings, fuselage, vertical tail, etc., are depicted to the right and left of the center of the display. During the air-to-air combat trials, the aircraft canopy outline remains fixed in the cone display, while the outside points move relative to the pilot's own canopy outline. The characteristics of the aggressor threat stations displays remained constant throughout all trials of the evaluation.

3.3 Simulation Models

The gun and gunsight models were identical in both interface conditions. The gun model simulated a simplified 20 mm Gatling gun, with an initial loadout of 600 rounds of ammunition and a firing rate of 6000 rounds/min. In the Conventional condition, gun mode selection was indicated by an alphanumeric display that appeared at the top of the SSI - a "G" followed by the number of rounds (x10) remaining. Similarly, all of the HUD displays indicated gun mode by displaying this alphanumeric information. In contrast, gun mode selection in the virtually-augmented condition was confirmed by a color-coded symbol - a blue gun in the nose of the fighter aircraft icon - displayed in the SSI and was followed by a digital readout of the number of rounds remaining.

Both interface conditions were outfitted with four Medium Range Missiles (MRM) and four Short Range Missiles (SRM). The MRMs and SRMs were modeled as simple, air-to-air missiles that generated flight profiles, guidance characteristics, and limitations representative of contemporary air-to-air missiles. In the Conventional interface condition, the selection of the MRM and SRM mode was indicated by an alphanumeric display that appeared at the top of the SSI. That is, when a missile was selected the letter "M" or "S" - MRM and SRM respectively - appeared in the top left corner of the SSI and was followed by a digital readout of the number of available missiles. Similar alphanumeric information also appeared in the upper left corner of the HUD. In the virtually-augmented condition, pilots were able to verify their missile mode selection in two different ways. First, a color-coded symbol that appeared in the SSI was used to indicate missile mode selection. Specifically, if the SRM mode was selected, a short range missile icon in the SSI turned blue, and after it was deployed it disappeared from the SSI. In addition, an alphanumeric digital readout of the selected missile mode and count appeared in the upper-left corner of the SSI.

The conventional and virtually-augmented conditions both employed a simplified simulation of a modern pulse-Doppler (PD) air-to-air radar with Track-While-Scan (TWS), Single-Target Track (STT), and Close-In Combat (CIC) capabilities. The conventional crew station condition also included a Range-While-Search (RWS) mode. The CIC mode provided several options for establishing radar locks in short-range (within a 10 NM range), highly dynamic combat situations including Boresight (BST), Slewable Scan Lock (SSL), and Vertical Scan Lock (VSL). Additionally, the virtually-augmented condition included a HMD mode that permitted pilots to control the radar using their flight helmet.

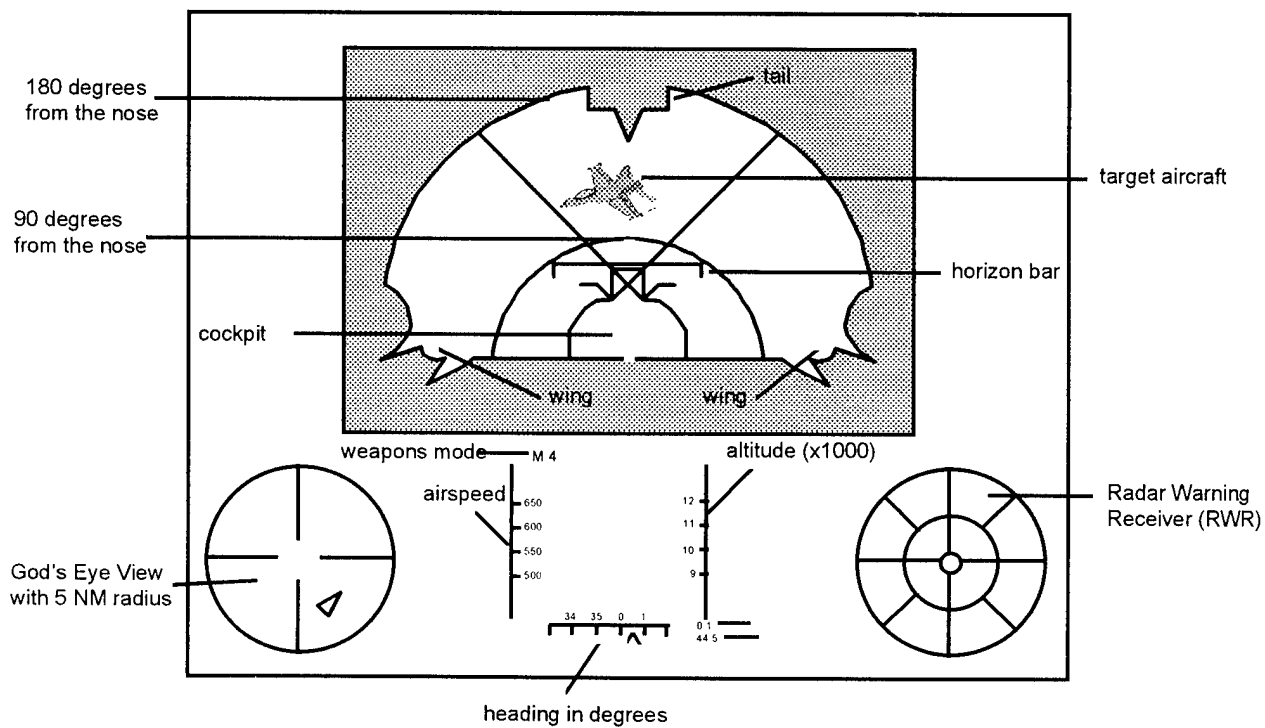


Figure 5. Threat Station Cone Display

The BST mode permitted pilots to quickly establish a radar lock on a target by positioning a "hot box" display, which appeared in the center of the HUD, within ± 2 deg of the target. The HMD mode in the virtually-augmented condition was analogous to the BST mode in the conventional condition except that the "hot box" was centered in the HMD display. Thus, pilots in the virtually-augmented condition were able to lock on a target by aligning it with their line of sight.

The RWS mode, which was only available in the conventional crew station condition, provided search-only capabilities representative of the search modes of typical current air-to-air radar, with analog display of contact positions and altitudes. The RWS mode permitted early and accurate target detection. Radar contacts were displayed as small rectangular blocks, and round target-history "dots" were used to aid in visualizing target movement.

The TWS mode permitted pilots to maintain simultaneous "track files" on multiple targets. In addition, the TWS mode provided pilots with information on target speed, altitude, course, and, in conjunction with the Target Identification System (TID), information on the class and type of target. The TWS mode permitted pilots to select a range scale of 10, 20, 40, 80, or 160 NM, an azimuth of $+10$, $+30$, and $+60$ deg, and rotate the radar antenna up or down 60 deg from level. The TWS mode also included an elevation bar option of 1-, 2-, 4-, or 8-bar scans.

The STT mode provided pilots with the greatest possible accuracy and information on a single target. Pilots were able to manually activate the STT mode from the RWS and TWS modes, or automatically from the CIC mode.

Both crew station conditions employed identical RWR models -- a highly simplified simulation, intended to represent typical performance capabilities and limitations of current operational RWR systems. The azimuth accuracy of the RWR model was ± 5 deg, while range accuracy was approximately $\pm 20\%$. The RWR model differentiated between various radar types (i.e., threat fighter, friendly fighter, bombers, air-to-air missiles), and operating modes (i.e., search or track).

The conventional crew station's RWR system was displayed on the upper right LCD of the HDD and was completely automatic. Symbols representing air-to-air threats appeared on the display indicating the approximate azimuth and range of the detected radar emitter. Increases in the strength of the threat's radar signal caused the threat symbol to move closer to the center of the RWR display. New emitter symbols on the RWR display blinked at a rate of 5 Hz for the first 4 sec, and were accompanied by an auditory warning signal - six, high-pitched, "beeps" - that were played over the pilot's headphones. Following the initial auditory warning signal, a tone that represented the pulse-repetition frequency (PRF) of the detected radar was played over the headset.

The virtually-augmented crew station's RWR system was also fully automatic, and did not have any associated controls. Detected emitters were indicated by colored "fans" that extended from the Own Aircraft symbol in the HDD along the azimuth of the emitter. Angular uncertainty and the estimated range of the detected signal were represented by the width and length of the "fans," respectively. The color of the "fan" denoted whether the emitter was classified as threat (red) or friendly (blue). Emitter type was represented by the pattern, pulse radar fans were single-hashed, and active AAMs generated solid fans. The fan's blink rate specified the operating mode of the emitter. Search and TWS emitters were identified by a fan that blinked at the sweep rate of the antenna, while STT mode was denoted by a steady fan.

The virtually-augmented RWR system employed the same auditory warning signals as the conventional system. However, warning tones in the virtually-augmented condition were localized with respect to the direction of the emitter. Additionally, the volume of the auditory tones varied inversely with the distance of the emitter.

The TID model was a highly simplified simulation intended to represent the current capabilities of both cooperative (transponder-based) and non-cooperative (radar-signature-based) target identification and recognition systems. The capabilities of the TID system were identical in the conventional and virtually-augmented crew station conditions, and both systems were completely automatic. The TID system was operational in either TWS or STT radar modes. Assuming the target has an operating transponder, classification (i.e., friendly or hostile) can be expected within a few seconds of establishing a track file (TWS) or lock (STT) out to the limits of the radar's detection capability. Identification (i.e., type) typically takes somewhat longer and is dependent on the range and aspect of the target.

4.0 DESCRIPTION OF EXPERIMENT

4.1 Subjects

Eighteen male pilots served as subjects. Eight of these pilots were from the United States, six were from France, and four were from the United Kingdom. Their ages ranged from 30 to 48 years with a mean age of 37 years. Eleven pilots had fighter aircraft experience including F-4, F-15, Jaguar, Mirage (F-1, 2000, III, V, CND), Rafale, and Tornado (IDS, ADV, GR1). Fighter aircraft hours ranged from 500 to 2,000 with a mean of 1353.18. Other aircraft experience included A-10, ACF, Alpha Jet, BAC1-11, Buccaneer, B-52, C141, CT-39, E-3, F-111, Gliders, Haines, Harrier, Hawk, Jet Provost, OA-37, O-2A, OV-10, P-3, T-2, T-34, T-37, T-38, TH-57, UV-18, and other small transport aircraft. Overall flight hours for the entire group ranged from 1720 - 4808 with a mean of 2980.4 hours. All pilots had normal or corrected-to-normal vision, and were not paid for their participation.

4.2 Simulated Air Combat Scenario

The task was to fly an air-to-air combat mission through hostile air space. The primary cockpit's task was to locate and destroy four computer controlled enemy bombers and egress to safe airspace. The scenario also included two independently manned hostile fighters (auxiliary stations) whose task was to eliminate the primary cockpit and defend the bombers. The scenario also included a computer controlled friendly F-15 fighter that flew a pre-determined route, but that did not deploy weapons.

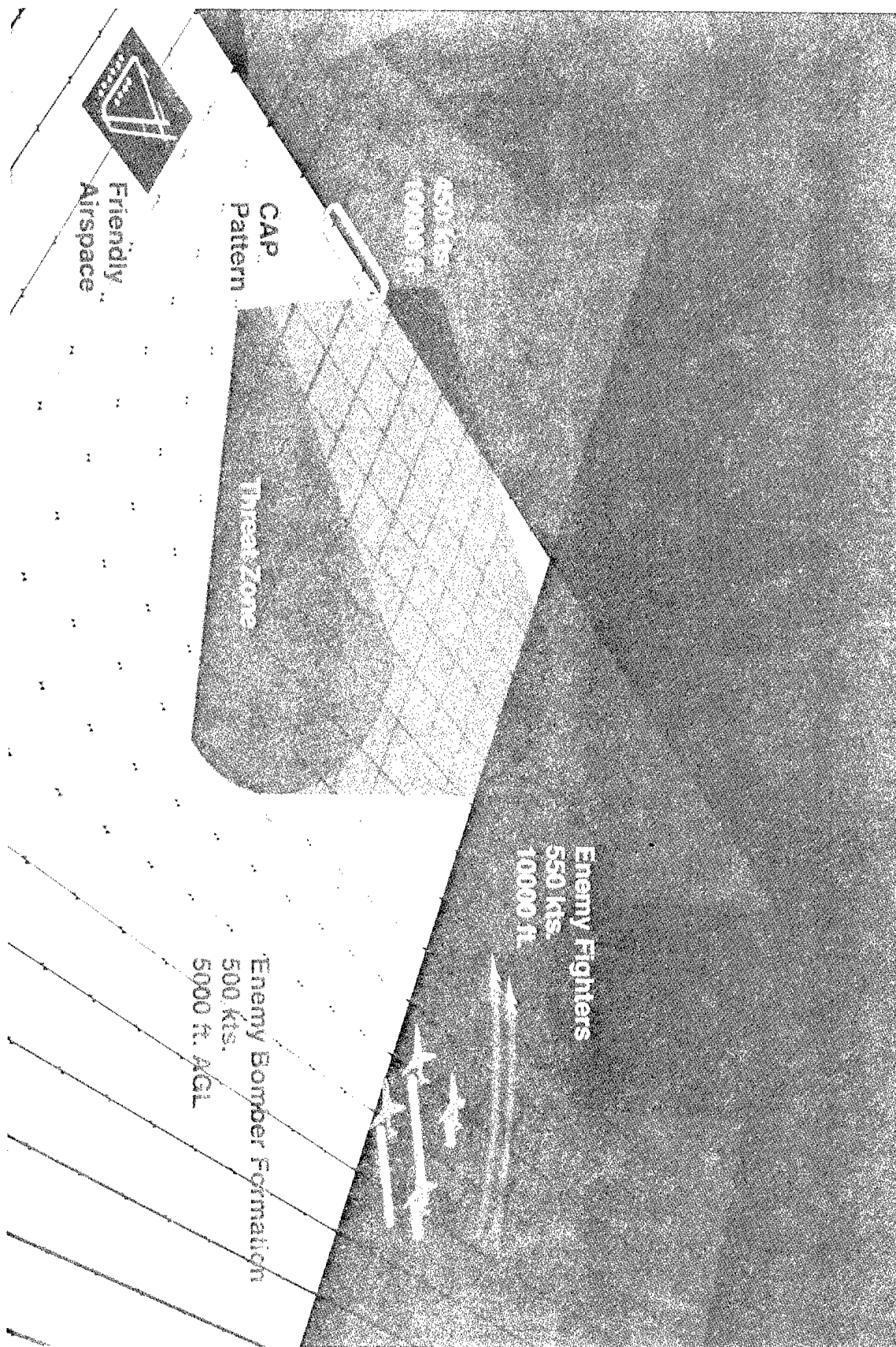
Each mission began with the primary cockpit flying a prescribed Combat Air Patrol (CAP) pattern and continued through the enemy intercept, weapons employment, and egress stages of the scenario. The mission was terminated if the primary cockpit was either shot down, ran out of fuel, or successfully destroyed all the bombers and returned to safe air space. The pilot of the primary cockpit was also allowed to terminate a mission at any time regardless of mission status.

A static depiction of the four phases of a representative scenario is provided in Color Plate 6.

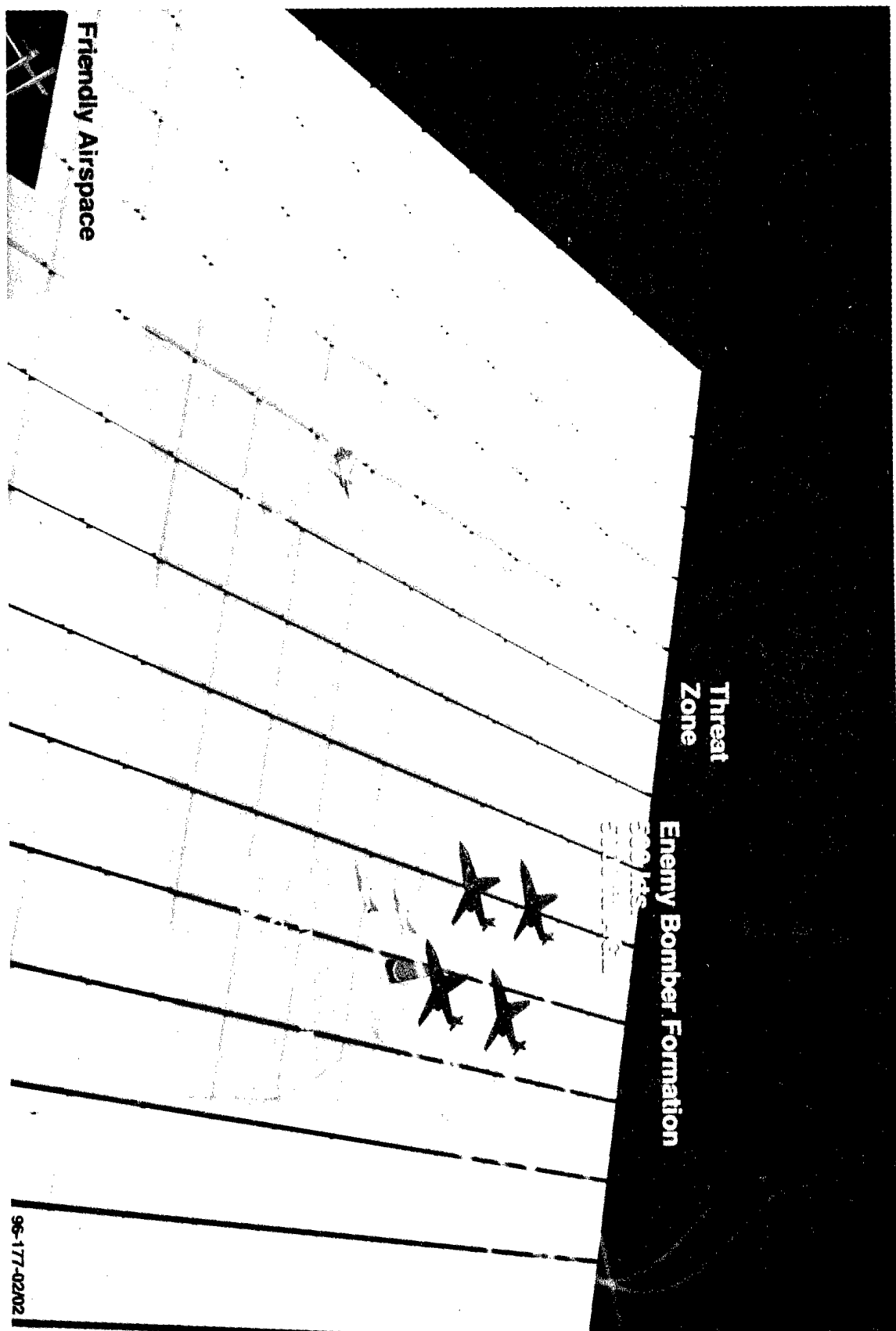
4.3 Rules of Engagement

Rules of engagement (ROE) were used to define the flight scenario and weapons engagement procedures. The ROE included rules for aviating, navigating, and communicating that were specific to each mission phase (See Appendix A for a complete ROE listing). The phases included the CAP, Intercept, Weapons Employment, Defensive Reaction, and Egress. Generally, a mission began with the CAP phase and ended with the egress phase. The ordering of the middle phases was, to a large extent, interchangeable and dependent upon the occurrence of events for each specific mission.

The ROE associated with the CAP phase were designed specifically for the target search task that began each mission. During this phase, pilots were expected to fly a prescribed pattern, maintain flight controls within prescribed limits, and search for enemy aircraft.



Color Plate 6. Four Phases of Simulated Mission - CAP

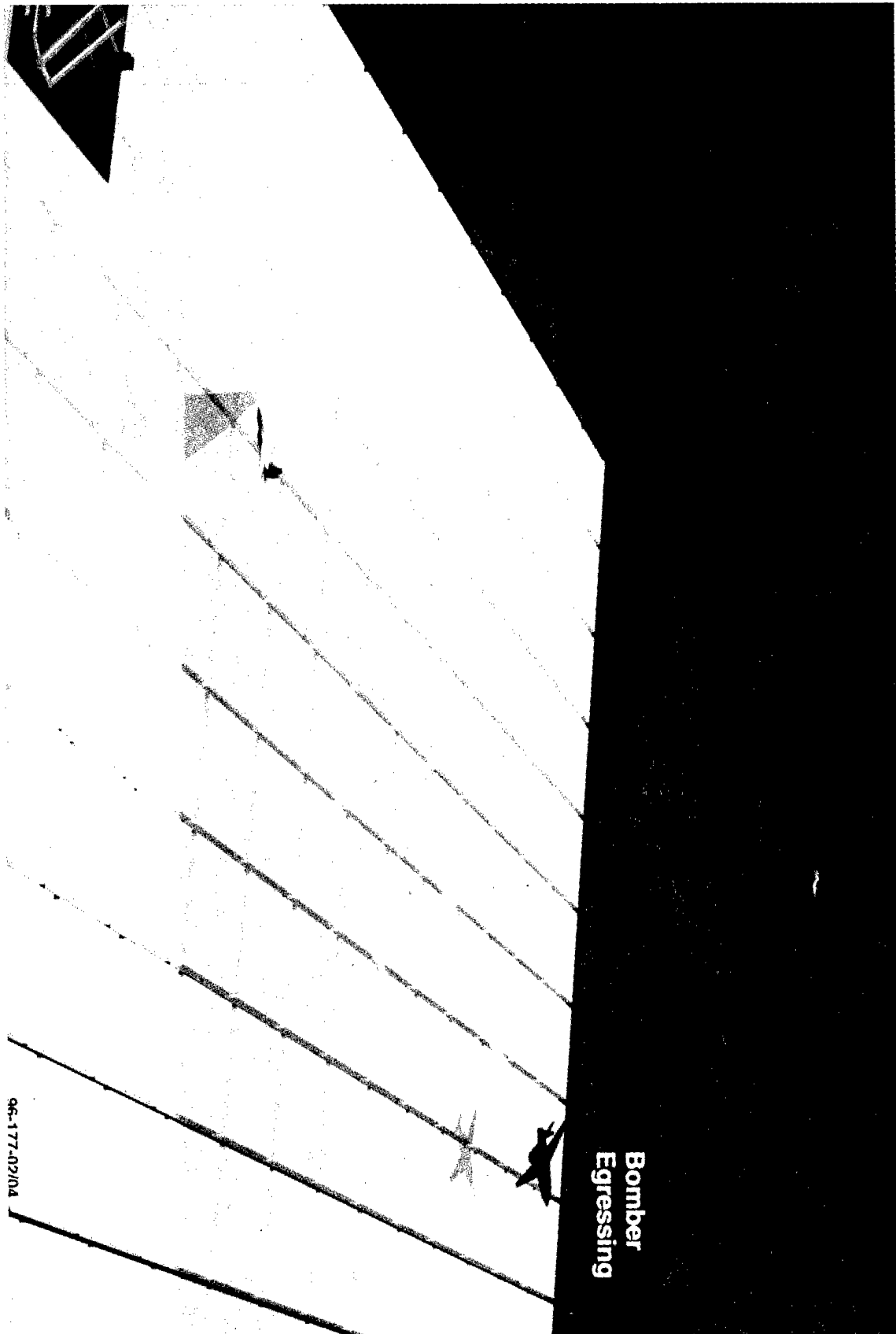


Color Plate 6. Four Phases of Simulated Mission - Intercept



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Color Plate 6. Four Phases of Simulated Mission - Weapon Employment



Color Plate 6. Four Phases of Simulated Mission - Egress.

The Intercept phase began with a commit call to attack an enemy. During the intercept phase, pilots were responsible for prioritizing multiple targets while monitoring the tactical situation closely. Pilots were expected to maintain aircraft controls within the limits specified by the ROE for this phase of the mission.

The ROE for the Weapons Employment phase included rules and control procedures specific to launching weapons. Pilots were expected to optimize each specific tactical situation while following the prescribed ROE.

The Defensive Reaction phase occurred only when specific "hostile" conditions were met. The ROE for this phase specified instructions for maximizing survival through the dynamic threat situation. The pilot was expected to follow the specific rules for maneuvering to reach safe airspace or an offensive condition.

The Egress phase began when all four of the hostile bombers were destroyed, all weapons were expended or "Joker" fuel state was reached. During this phase the primary goal was to return to safe airspace.

4.4 Performance Measures

Three classes of pilot performance measures were used to assess differences between the two crew station conditions. These classes of measures included: (1) Pilot-aircraft system output measures, defined as measures that reflect the observable, output characteristics of the human-machine system that are relevant to task performance, (2) workload measures, defined as measures that reflect the general level of cognitive effort being expended at any given point in time, and (3) situation awareness measures, defined by Endsley (1990) as measures that reflects the quality of a pilot's perception of critical environmental/task elements within an operationally meaningful volume of time and space, the comprehension of their meaning, and the projection of their status in the near future.

4.4.1 Pilot-aircraft system output measures

Two classes of system output measures, reflecting both "lower-order" and "higher-order" levels of performance description, were collected as part of this evaluation. Lower-order measures consisted of the state parameters of all aircraft (e.g., altitude, airspeed, xyz coordinates, etc.), radar parameters (e.g., mode selected, azimuth selected, elevation bars selected, etc.), missile parameters (e.g., number available, number fired, range of target at missile launch, etc.), and defensive countermeasures (e.g., number of chaff and flares and time deployed, etc.). These measures were continuously recorded by computer for all trials in the evaluation. A complete listing of these measures is provided in Appendix B.

Higher-order measures were derived as combinations of the lower-order measures. While the latter indexed instantaneous states of the various elements of the simulated air combat scenario, the former indexed more global indices of overall mission performance. Among the classes of higher-order measures that were collected and analyzed as part of the current evaluation were the following:

Bomber Kills. This refers to the number of enemy bombers destroyed by the primary cockpit.

Threat Kills. This refers to the number of enemy fighters destroyed by the primary cockpit.

Overall Outcome. This refers to the outcome of the missions (i.e., a “win” or “loss”) at a global level. A “win” was defined as any mission in which the primary cockpit successfully destroyed all four of the enemy bombers, and returned to safe airspace. All other mission results (e.g., accidental ground strike, primary cockpit destroyed by threat fighters) were defined as “losses.”

Success Ratio. This measure was calculated as the number of successful missions for the primary cockpit (e.g., trials resulting in Wins) divided by the number of successful missions for the enemy fighters (e.g., trials in which the threat fighters shot down the primary cockpit).

Ground Collisions. This measure refers to the number of missions in which the primary cockpits impacted the ground during the performance of the missions.

Fratricides. Fratricides refers to the frequency with which the primary cockpit engaged and destroyed the friendly F-15 fighter.

Missile Shots. This measure corresponds to the amount of ordnance expended by the primary cockpit, expressed as a percentage of the total amount of ordnance available. In addition, missile effectiveness was derived as a percentage of the number of missiles that achieved hits, out of the total number of missiles fired.

Target range at missile launch. This measure refers to the distance of the primary cockpit from the enemy aircraft when missiles were launched.

Mission Length. This measure refers to the mean mission length, sorted by tactical state. Tactical state refers to offensive and defensive missions. Trials in which the primary cockpit deployed the first shot were defined as offensive missions. Trials in which the threat stations deployed the first shot were defined as defensive missions.

4.4.2 Workload measures

The *Subjective Workload Assessment Technique* (SWAT) (Reid, Potter & Bressler, 1989) was used to assess the workload experienced by pilots in both crew station conditions as well as the pilots operating the threat stations. The SWAT assumes that workload is a multidimensional construct consisting of time load, mental effort load, and psychological stress load. Each of these dimensions was rated on three levels: low, medium, and high. SWAT ratings were obtained from the pilots in the primary cockpit and the threat stations after every three trials. A copy of the SWAT rating forms may be found in Appendix C.

The *Subjective Workload Dominance Technique* (SWORD) (Vidulich, Ward & Schueren 1991) was used to assess the workload associated with the two cockpit configurations across

mission phases. The SWORD is a workload assessment technique that uses a series of relative judgments comparing the workload of different task conditions. The pilots rated the workload for both the conventional and virtually-augmented crew stations across the CAP, intercept, weapons employment, and egress phases during a debrief meeting after the evaluation was completed. A copy of the SWORD rating scale may be found in Appendix D.

4.4.3 Situation awareness measures

The *Situation Awareness Rating Technique* (SART) (Taylor, 1990) was used to assess situation awareness associated with flying the threat stations. The SART is a multidimensional scale in which pilots rate the demand on their attentional resources, the available supply of attentional resources, and their understanding of the situation. These dimensions are combined to assess the pilot's knowledge of a situation. SART ratings were obtained from the pilots in the threat stations after every three trials. A copy of the SART rating form may be found in Appendix E.

The *Cognitive Compatibility Situation Awareness Rating Technique* (CC-SART) (Taylor, 1995) was used to assess situation awareness associated with flying the primary cockpit. Cognitive compatibility refers to the congruence or consistency between the ways in which tasks and situations are presented. Events that occur within the realm of human expectation are considered cognitively compatible. Three dimensions are rated on the CC-SART including: (1) level of processing, (2) ease of reasoning, and (3) activation of knowledge. These dimensions were rated by pilots in the virtually-augmented and conventional crew station conditions following every third trial. A copy of the CC-SART rating form may be found in Appendix F.

The *13 Dimension Cognitive Compatibility Situation Awareness Rating Technique* (13 D CC-SART) (Taylor, 1990) was used to assess situation awareness associated with the use of the two crew station configurations across mission phases. The 13D CC-SART is a multidimensional, self-report scale that uses 13 dimensions thought to be relevant to situation awareness (e.g., the intuitiveness and the straightforwardness of an interface.) The pilots completed the 13 D CC-SART after the evaluation was completed. A copy of the 13 D CC-SART rating form may be found in Appendix G.

4.4.4 Debrief questionnaire

In addition to the above 3 classes of measures, a 91-item questionnaire was administered to the participants following the completion of data collection during a debriefing interview. The questionnaire was designed to elicit pilots' subjective impressions concerning many aspects of the evaluation. The questionnaire included both quantitative items (which required a numerical rating), and more qualitative items (which required a short-answer type response). A copy of the debrief questionnaire may be found in Appendix H.

4.5 Experimental Design

Two crew station interface designs (virtually-augmented, conventional) were combined factorially with three initial threat altitudes (low, medium, and high) to provide six unique experimental conditions. These conditions were manipulated within subjects; thus, every pilot performed the evaluation in each of the six possible conditions. The presentation sequence of the

conditions was counterbalanced to guard against order effects. The presentation sequence may be reviewed in Appendix I.

4.6 Procedure

4.6.1 Training procedure

Each pilot received approximately 8 hours of training prior to data collection. This time included a review of training manuals relevant to both the simulator and the rules of engagement, and included practice flying both the virtually-augmented and conventional primary cockpits and the threat station auxiliary cockpit. The pilots were provided with the training manuals for individual study prior to entering the laboratory. Simulator specific training began with the conventional crew station since this mode was most familiar to the pilots, and included display and control functionality, and progressed to a full mission rehearsal while the pilot was tutored by a subject matter expert. Next, the virtually-augmented crew station was introduced and the in-simulator training was repeated using the novel interface.

The majority of in-simulator training time was dedicated to full mission rehearsal. This included practice intercepts and close-in combat modes. Training was concluded after pilots had been thoroughly briefed on the scenario, the displays and controls, and the relevant rules of engagement. Copies of the manuals provided to pilots during training are included as Appendix J.

4.6.2 Testing procedure

Each of the eight US pilots participated in 18 simulated air intercept missions in the primary cockpit. Due to time constraints, the remaining ten pilots from the RAF and French Air Force participated in 12 simulated missions in the primary cockpit. Each pilot flew half of their simulated trials using the virtually-augmented crew station configuration, and half using the conventional crew station configuration. Each pilot also participated in several trials as the pilot of a hostile fighter when they were not assigned to the primary cockpit. Following the completion of data collection, the pilots completed the debrief questionnaire, the SWORD workload assessment, and the 13 D CC-SART SA rating scales during a debriefing session.

5.0 RESULTS

To the extent possible, repeated measures analyses of variance (ANOVA) were conducted on each of the performance measures assessed as part of this evaluation. However, some variables produced conditions that violated the assumptions necessary for the ANOVA to be a valid test. In these cases, an alternative, non-parametric test of statistical significance test was identified and performed. All results discussed in this section were found to be statistically significant at the $p < .10$ level or better unless otherwise indicated.

5.1 Pilot - Aircraft System Output Measures

5.1.1 Bomber kills

Bomber kills refer to the number of bombers successfully destroyed by the primary cockpit. The mean percentages of bombers killed by the primary cockpit are presented in Table 3. These data were subjected to a 2 factor (crew station configuration) repeated measures ANOVA procedure that failed to yield a statistically significant main effect. An examination of Table 3 reveals that the mean percentage of bombers killed by the virtually-augmented crew station was 53.3%, whereas the mean percentage of bombers killed by the conventional crew station configuration was similar at 54.6%.

Table 3.

Percentage of Enemy Bombers Killed as a Function of Crew Station Configuration

Crew Station Configuration	Enemy Bombers Killed (%)
Virtually-Augmented	53.3
Conventional	54.6

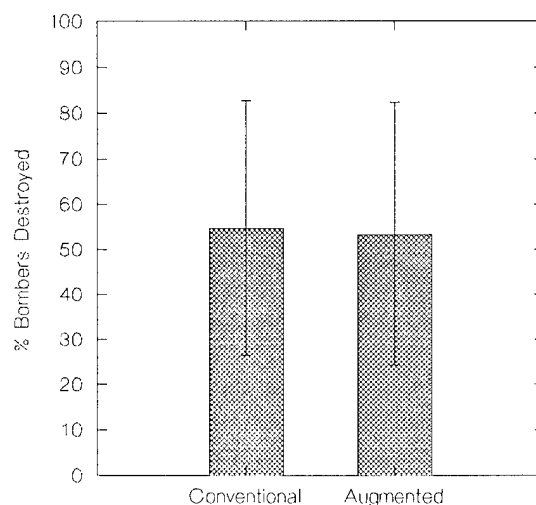


Figure 6. Percentage of Bomber "Kills" by Crew Station Configuration

5.1.2 Threat kills

Threat kills refers to the number of enemy fighters that were destroyed by the primary cockpit during the performance of the intercept mission. The mean percentages of enemy fighters killed by the primary cockpit are presented in Table 4. These data were subjected to a 2 factor (crew station configuration) repeated measures ANOVA procedure that failed to yield any statistically significant main effect. An examination of Table 4 reveals that 9.9% of the threat fighters were destroyed when the virtually-augmented crew station configuration, was used as compared to 8.5% of threat fighters destroyed when the conventional crew station configuration was used.

Table 4.
Percentage of Enemy Fighters Killed as a Function of Crew Station Configuration

Crew Station Configuration	Threat Fighters Killed (%)
Virtually-Augmented	9.9
Conventional	8.5

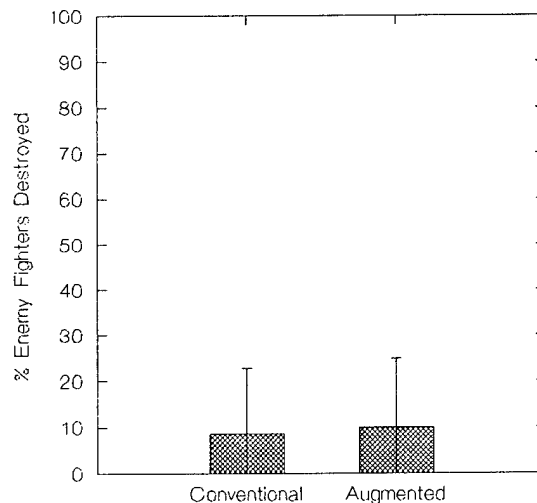


Figure 7. Percentage of Enemy Fighter “Kills” by Crew Station Configuration

5.1.3 Overall outcome

A mission was defined as a win if the primary cockpit intercepted and destroyed all four of the enemy bombers and returned to safe airspace. All other mission outcomes were defined as losses. Mission outcome data, which are presented in Table 5, were analyzed using a Chi-Square test for independence. The analysis revealed a statistically significant difference between the virtually-augmented and conventional crew station configurations, $\chi^2 (1, n=263) = 5.42, p < .05$. An examination of Table 5 reveals that the virtually-augmented crew station configuration resulted in wins on 28 out of 132 trials (21.2%), whereas the performance in the conventional crew station was significantly worse, with only 14 wins out of 131 missions (10.7%).

Table 5.
Mission Outcome as a Function of Crew Station Configuration

Crew Station Configuration	Outcome N (%)	
	Win	Loss
Virtually-Augmented	28 (21.2)	104 (78.8)
Conventional	14 (10.7)	117 (89.3)

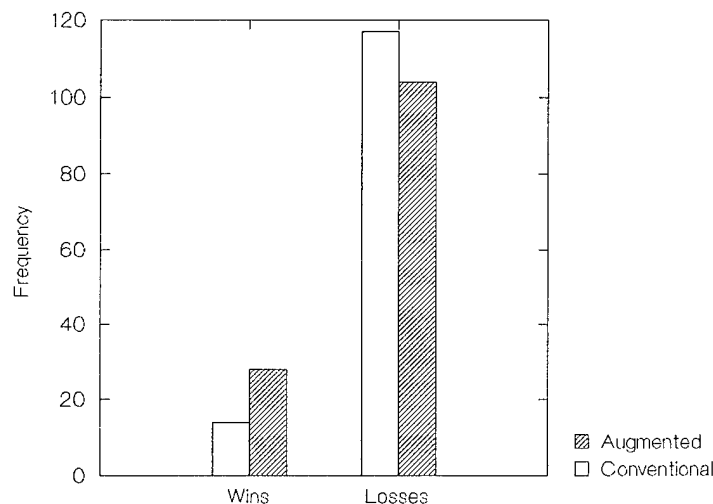


Figure 8. Mission Outcome by Crew Station Configuration.

5.1.4 Exchange ratio

The exchange ratio is a means of describing overall campaign effectiveness for the primary cockpit, expressed as a function of the effectiveness of the threat stations. The exchange ratio presented here is defined as the number of successful missions completed by the primary cockpit, divided by the number of successful missions for the threat fighters. A successful mission for the primary cockpit was defined previously (e.g., trials resulting in “wins”). A successful mission for the threat fighters was defined as a trial in which the threat fighter shot down the primary cockpit (e.g., those primary cockpit “losses” directly attributable to combat engagements with the enemy). The exchange ratio observed for each crew station configuration is presented in Table 6. These data were analyzed using a Chi-Square test for independence. This analysis revealed a statistically significant difference between the virtually-augmented and conventional crew station configurations, $X^2 (1, n=220) = 4.32, p < .05$. An examination of the means reveals an exchange ratio for the virtually-augmented crew station configuration (.322) that was significantly higher than that observed for the conventional crew station configuration (.154).

Table 6.
Exchange Ratio as a Function of Crew Station Configuration

Crew Station Configuration	Exchange Ratio
Virtually-Augmented	.322
Conventional	.154

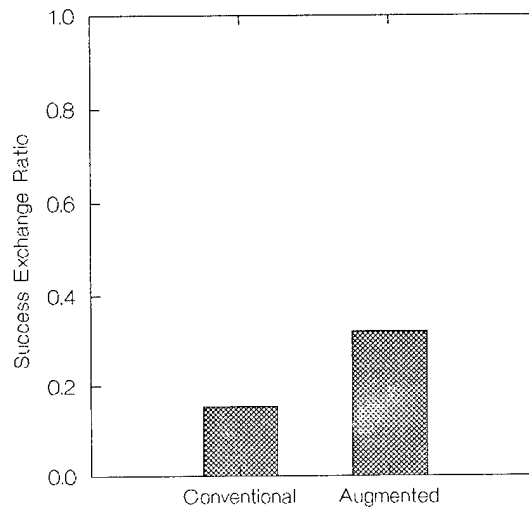


Figure 9. Exchange Ratio by Crew Station Configuration.

5.1.5 Ground collision

The frequency with which the primary cockpit experienced catastrophic ground collisions is presented in Table 7. These data were subjected to a paired comparison t-test. The analysis yielded a statistically significant difference between the virtually-augmented and conventional crew station configurations $t(17) = -.343$, $p < .01$, two-tailed. An examination of Table 7 reveals that only 2 out of 132 missions (1.5%) flown with the virtually-augmented crew station ended with a ground collision. Comparatively, 13 out of 132 missions (9.85%) flown with the conventional crew station resulted in ground collisions.

Table 7.
Number of Ground Collisions as a Function of Crew Station Configuration.

Crew Station Configuration	Frequency of Crashes N (%)
Virtually-Augmented	2 (1.5)
Conventional	13 (9.85)

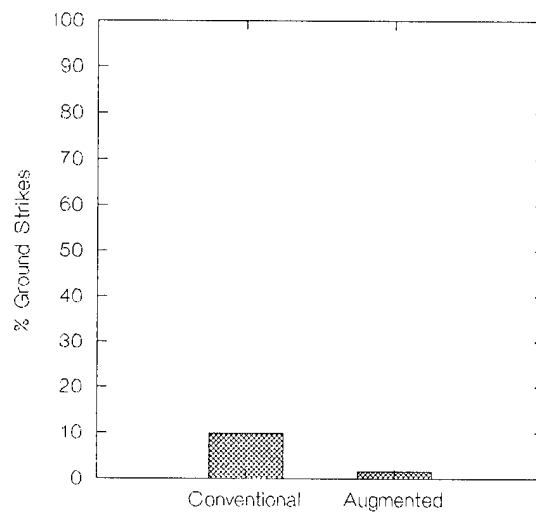


Figure 10. Ground Collisions by Crew Station Configuration

5.1.6 Fatricides

Fatricides were defined as any event in which the primary cockpit engaged and shot down the computer controlled “friendly” F-15. The frequency with which this occurred is presented in Table 8, an examination of which reveals no difference between crew station configurations in the number of fratricidal incidents.

Table 8.

Frequency of Fratricide Events as a Function of Crew Station Configuration

Crew Station Configuration	Number of Fratricides
Virtually-Augmented	3
Conventional	3

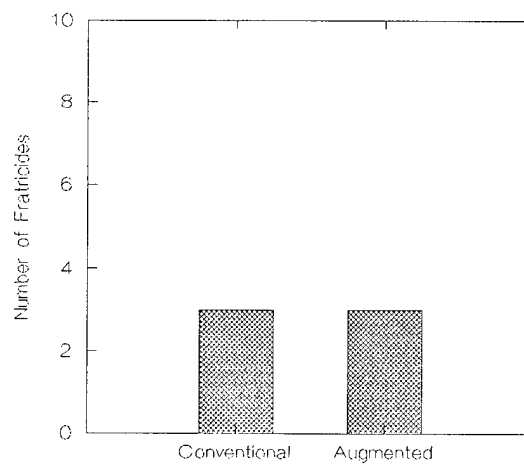


Figure 11. Number of Fratricides by Crew Station Configuration

5.1.7 Missile shots

The amount of ordnance expended by the primary cockpit was expressed in terms of a percentage of missiles fired out of the total number of missiles available. These data are presented in Table 9. Paired comparison t-tests were performed on the average percentage of missiles fired as a function of primary cockpit type. These t-tests revealed a statistically significant difference in the percentage of short range missiles fired between the crew station configurations, $t(17) = 3.477$, $p < .01$. An examination of Table 9 reveals that 20.6% of the total short range missiles available were fired in the virtually-augmented crew station configuration as compared to only 9.3% of available short range missiles fired in the conventional crew station configuration. Conversely, there was little difference in the percentages of the medium range missiles fired between the cockpit conditions. Table 9 indicates that 82% of available medium range missiles were fired from the virtually-augmented crew station configuration, as compared to 83.7% of available medium range missiles fired from the conventional crew station configuration. Finally, Table 9 also illustrates little difference in missile effectiveness as a function of crew station configuration. There is a slight advantage for missiles hitting their targets when fired from the conventional crew station, but this difference failed to achieve statistical significance.

Table 9.
Ordnance Expended and Effectiveness as a Function of Crew Station Configuration

Crew Station Configuration	SRM Fired # (%)	SRM Hits # (%)	MRM Fired # (%)	MRM Hits # (%)
Virtually-Augmented	109 (20.6)	51 (46.8)	433 (82.0)	257 (59.4)
Conventional	49 (9.3)	27 (55.1)	442 (83.7)	290 (65.6)

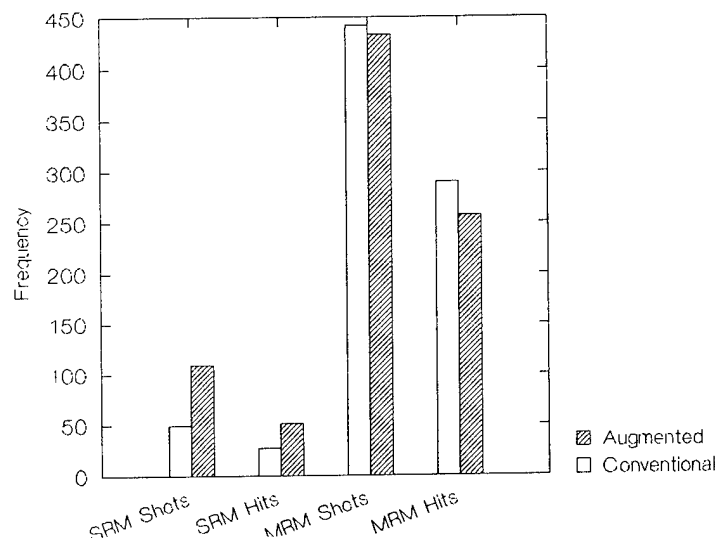


Figure 12. Ordnance Expended by Crew Station Configuration

5.1.8 Target range at missile launch

The ranges from the primary cockpit to engaged target for the short range and medium range missiles are presented in Table 10. An examination of the Table reveals little difference between the virtually-augmented and conventional crew stations in the distance from which ordnance was deployed. The mean distance for short range missiles (in nautical miles) was 1.53 NM for the virtually-augmented crew station, and 1.31 NM for the conventional crew station. Similarly, the mean range for medium range missile shots in the virtually-augmented crew station was 17.5 NM and 18 NM for the conventional crew station. It is interesting to note that every pilot launched medium range missiles in both virtually-augmented and conventional crew station configurations. However, 39% of pilots in the conventional crew station failed to launch a single short range missile, whereas only 10% of pilots in the virtually-augmented crew station failed to launch any short range missiles.

Table 10.

Range of Ordnance Deployment (NM) as a Function of Crew Station Configuration

Crew Station Configuration	SRM Range (NM)	MRM Range (NM)
Virtually-Augmented	1.53	17.47
Conventional	1.32	18.01

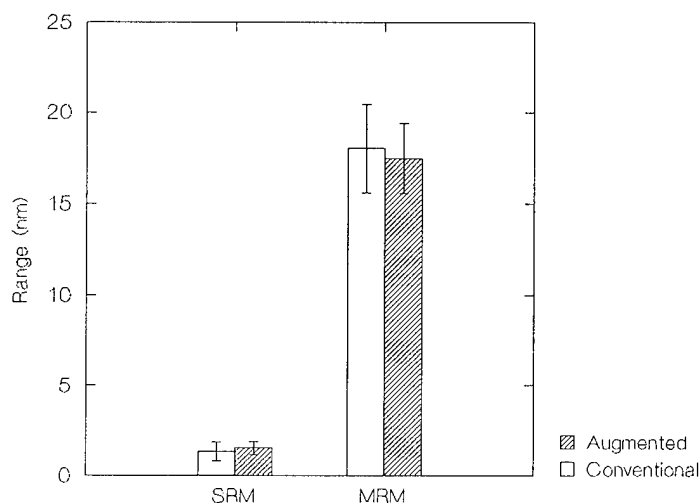


Figure 13. Target Range by Weapon and Crew Station Configuration

5.1.9 Mean life expectancy per mission

Mean life expectancy refers to the average length of a trial as a function of crew station configuration. These data are categorized into “offensive” and “defensive” missions. An offensive mission refers to a mission in which the primary cockpit deployed the first shot, while a defensive mission was defined as one in which one of the threat fighters deployed the first shot. The data from two pilots were dropped prior to this analysis because they contributed no data to one cell in

the design. The data are presented in Table 11. A 2 (first shooter) x 2 (crew station configuration) repeated measures ANOVA procedure was performed on the data. This analysis revealed a statistically significant main effect of crew station configuration, $F(1, 15) = 6.715, p < .02$. An examination of the means in Table 11 reveals that the average mission length for the virtually-augmented crew station was 7.35 minutes, as compared to the significantly shorter mission length of 6.13 minutes for the conventional crew station. Table 11 also indicates that during defensive missions, the virtually-augmented crew station configuration resulted in mission lengths an average of 1 minute and 44 seconds longer than the conventional crew station configuration.

Table 11.

Length of Mission as a Function of Crew Station Configuration and Tactical State.

Crew Station Configuration	Length of Offensive trials (#)	Length of Defensive trials (#)
Virtually-Augmented	6.83 (73)	7.86 (47)
Conventional	6.14 (76)	6.12 (43)

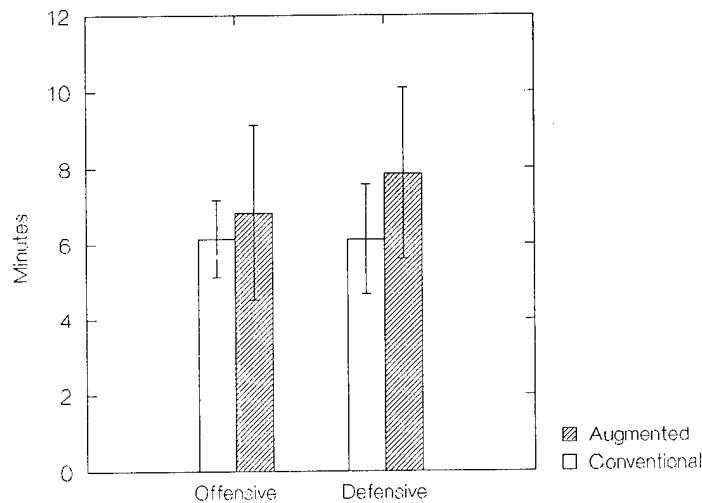


Figure 14. Mission Length by Crew Station Configuration and Tactical State.

5.2 Workload Measures

5.2.1 Subjective Workload Dominance Technique (SWORD)

The SWORD rating procedure was conducted at the conclusion of each pilot's final session. The SWORD is a bipolar rating technique with a scale from -1 to 0 to +1. A rating of 0 indicates no difference in the workload between two conditions. Negative values indicate higher workload associated with one condition, while positive values indicate higher workload associated with a second condition. The higher ratings (positive or negative) indicate higher levels of workload. A 2 (crew station configuration) x 4 (mission phase) repeated measures ANOVA procedure performed on these data yielded a statistically significant main effect for crew station

configuration, $F(1,17) = 9.138, p < .01$. An examination of the means revealed that workload was rated significantly higher for the conventional crew station (.1512) than for the virtually-augmented crew station (.0988). The ANOVA also yielded a statistically significant main effect for Mission Phase, $F(3,51) = 30.014, p < .01$. The mean workload ratings for each phase may be found in Table 12. Interestingly, Table 12 illustrates that the workload associated with the task increased throughout the first three mission phases, with the Weapons Employment phase receiving the highest workload rating. Following the Weapons Employment phase, the workload ratings dropped off for the Egress phase.

Table 12.
SWORD Workload Ratings x Mission Phase.

Mission Phase.	Mean SWORD Rating.
CAP	.0606
Intercept	.1228
Weapons Employment	.2381
Egress	.0785

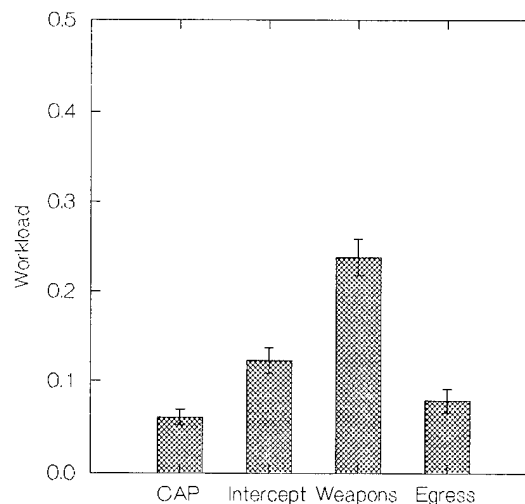


Figure 15. SWORD Workload Rating by Mission Phase.

5.2.2 Subjective Workload Assessment Technique (SWAT)

5.2.2.1 Primary cockpit.

Each pilot completed the SWAT rating form after every three trials. The SWAT requires a rating from 1 (lowest) to 3 (highest) demand on three dimensions: Time Demand; Mental Demand; and Psychological Demand. The raw data were then collapsed across pilots to produce a mean workload rating from each pilot on each of the three dimensions, for each cockpit. These data may be found in Table 13, an examination of which reveals few differences between the crew station configurations on any of the three rated dimensions. The raw workload rankings on the three dimensions were then used to obtain a converted score for each pilot within each cockpit. A paired comparisons t-test was performed on the converted scores. The analysis failed to yield any

statistically significant differences between the crew station configurations, $t(17) = -.075$, $p < .94$, two-tailed.

Table 13.
SWAT Rankings as a Function of Crew Station Configuration

Crew Station Configuration	Workload Dimension		
	Time Demand	Mental Demand	Psychological Demand
Virtually-Augmented	2.3	2.16	2.11
Conventional	2.25	2.23	2.08

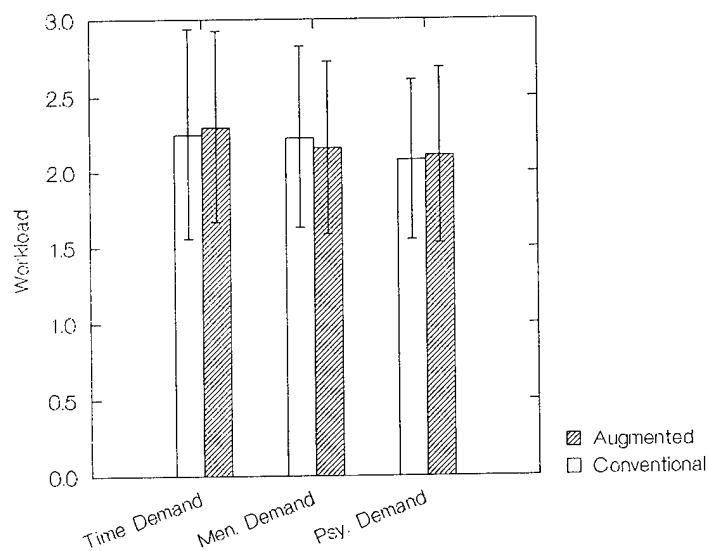


Figure 16. Primary Cockpit SWAT Workload Ratings by Crew Station Configuration.

5.2.2.2 Threat stations.

Each threat station pilot completed the SWAT rating form after every three missions flown by the primary cockpit. The SWAT requires a rating from 1 (lowest) to 3 (highest) demand on three dimensions: Time Demand; Mental Demand; and Psychological Demand. The raw data were then collapsed across pilots to produce a mean workload rating from each pilot on each of the three dimensions, as a function of the primary cockpit they flew against. These data are summarized in Table 14. An examination of Table 14 reveals few differences between the two crew station configurations. The raw workload rankings on the three dimensions were then used to obtain a converted score for each pilot. A t-test was performed on the converted scores between the two crew station configurations. The analysis failed to yield any statistically significant difference between the virtually-augmented and conventional crew station configurations, $t(17) = -.63$, $p < .53$, two-tailed.

Table 14.
SWAT Rankings as a Function of Opposing Primary Crew Station Configuration.

Crew Station Configuration	Workload Dimension		
	Time Demand	Mental Demand	Psychological Demand
Virtually-Augmented	1.76	1.89	1.45
Conventional	1.73	1.85	1.56

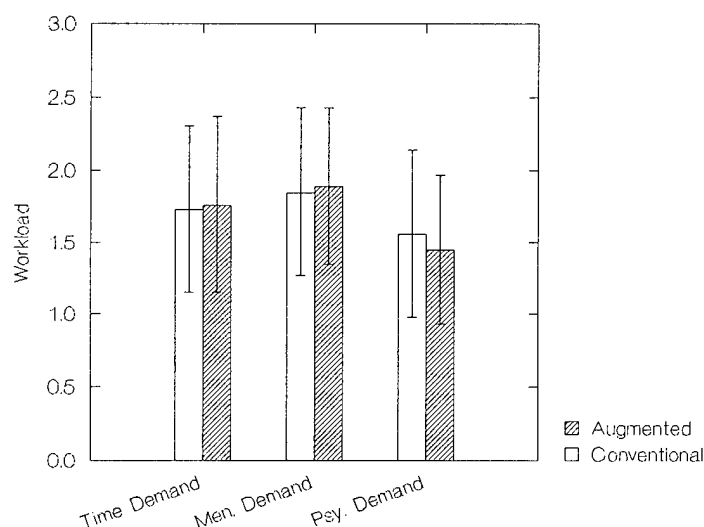


Figure 17. Threat Station SWAT Workload Ratings by Opposing Crew Station Configuration.

5.3 Situation Awareness Measures

5.3.1 Cognitive Compatibility Situation Awareness Rating Technique (CC-SART)

Each primary cockpit pilot completed the CC-SART rating form after every three missions. The CC SART requires a rating on a scale from 1 (lowest) to 7 (highest) on three dimensions: Level of Processing required to complete the task (in which lower ratings are better); Ease of Reasoning, and Activation of Knowledge (in which higher ratings are better). These data were then collapsed across pilots to produce a mean rating for each of the three CC-SART dimensions, for each crew station configuration, for each pilot. The resultant means are presented in Table 15. Prior to data analysis, the ratings for the Level of Processing dimension were normalized in order to reflect a scale in which higher ratings indicated better performance. A 2 (crew station configuration) x 3 (rating dimensions) repeated measures ANOVA procedure performed on the data yielded a significant main effect for crew station configuration, $F(1, 17) = 3.08$, $p < .09$. An examination of Table 15 reveals a mean SA rating of 4.5 for the virtually-

augmented crew station and 4.0 for the conventional crew station. The analysis also revealed as significant interaction of crew station configuration x rating dimension, $F(2,34) = 2.97$, $p < .079$. An examination of Table 15 reveals a consistent advantage for the virtually-augmented crew station over the conventional crew station (e.g., lower level of processing required; higher ease of reasoning; and higher activation of knowledge).

Table 15
CC-SART Ratings as a Function of Crew Station Configuration

Crew Station Configuration	Rating Dimension		
	Level of Processing	Ease of Reasoning	Activation of Knowledge
Virtually-Augmented	3.769	4.472	4.694
Conventional	4.148	3.833	4.343

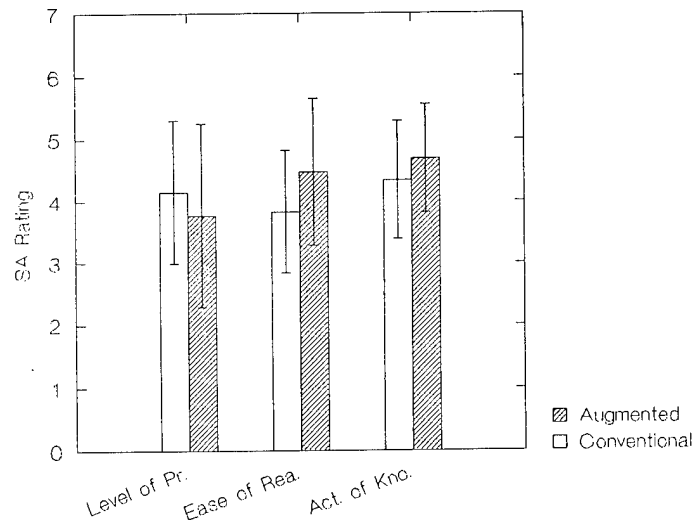


Figure 18. CC-SART SA Rating by Crew Station Configuration.

5.3.2 Situation Awareness Rating Technique (SART)

Each threat station pilot completed the SART rating form after every three missions flown by the primary cockpit. The SART requires a numerical rating on a scale from 1 (lowest) to 7 (highest) on four dimensions: Demand on attentional resources, Supply of attentional resources, Understanding of the situation, and Situation Awareness. These data were then collapsed across pilots to produce a mean rating for each of the four SART dimensions for the pilots flying against the primary cockpit in each of the crew station configurations. These data are summarized in Table 16. A 2 (crew station configuration) x 4 (rating dimensions) repeated measures ANOVA procedure performed on the data revealed a significant main effect of Rating Dimension, $F(3,51) = 3.096$, $p < .08$. There were no other statistically significant main effects or interactions observed in this particular data set. An examination of the means presented in Table 16 reveals that the mean rating for the Demand dimension was rated slightly lower (4.04) than either Supply (4.8) or

Understanding (4.8) dimensions. The mean rating for SA was intermediate to these two groupings, with a mean rating of 4.54.

Table 16

Threat Station SART Ratings as a Function of Opposing Crew Station Configuration

Crew Station Configuration	Rating Dimension			
	Demand	Supply	Understanding	Situation Awareness
Virtually-Augmented	4.06	4.77	4.73	4.48
Conventional	4.01	4.82	4.83	4.59

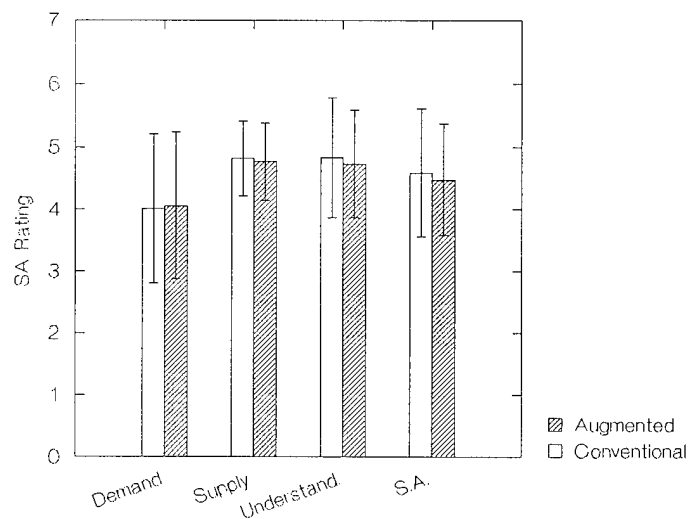


Figure 19. Threat Station SART SA Rating by Opposing Crew Station Configuration.

5.3.3 13-D Cognitive Compatibility-Situation Awareness Rating Technique

The 13-D CC-SART rating procedure was completed at the conclusion of each pilot's final session. This technique enabled the determination of a mean subjective rating, for each crew station configuration within each mission phase, of 13 dimensions of system design that are thought to influence a pilot's SA (e.g., intuitiveness of the interface, confusability of the interface). Each dimension is rated on a scale from 1 (lowest) to 7 (highest). It is important to note that higher ratings do not always correspond to "better" ratings. For example, on the Confusability dimension, a higher rating would indicate more confusion, thus a less favorable rating. In order to analyze the data, those items in which higher ratings represent worse performance were normalized such that higher ratings actually represent better performance. These data were subjected to a 2 (crew station configuration) x 4 (mission phase) x 13 (rating dimension) repeated measures ANOVA procedure that revealed a statistically significant main effect for crew station configuration, $F(1,17) = 7.514$, $p < .01$. An examination of the means revealed that pilots rated SA significantly higher for the virtually-augmented crew station with a mean rating of 5.235 than for the conventional crew station, with a mean rating of 4.727. The ANOVA also yielded a

statistically significant main effect for Mission Phase, $F(3, 51) = 13.177, p < .01$. The mean SA ratings for each mission phase may be found in Table 17. An examination of Table 17 reveals that pilots rated their SA higher for the CAP and the Egress phases, when there was somewhat less activity for them to consider, and lower for the combat phases (Intercept and Weapons Employment) when a multitude of simultaneous events demanded attention. A post-hoc analysis revealed that the SA ratings obtained for the CAP and Egress phases were both significantly different than the Intercept and Weapons Employment phases, $p < .01$, but were not significantly different from each other. Furthermore, the Intercept and the Weapons Employment phases were also not significantly different from one another.

Table 17.
13 D CC-SART Situation Awareness Ratings by Mission Phase.

Mission Phase.	Mean SA Rating.
CAP	5.25
Intercept	4.74
Weapons Employment	4.52
Egress	5.40

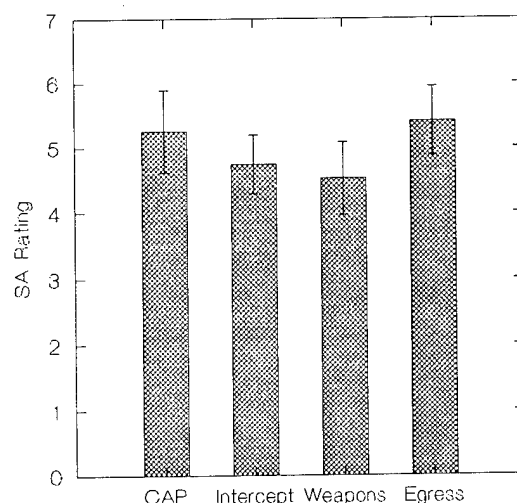


Figure 20. 13D CC-SART SA Rating by Mission Phase.

Following the initial analysis, each of the rated dimensions of the scale were examined. An average rating was calculated by cockpit for each of the four ratings made by each pilot, on each dimension. These data were not normalized for this analysis. The means for each cockpit on each dimension were then subjected to paired comparison t-tests. These analyses yielded statistically significant differences between the cockpits on nine of the 13 dimensions, $p < .1$. Table 18 presents the means for each rating dimension by cockpit configuration. An examination of Table 18 reveals an advantage for the Virtually-Augmented cockpit over the Conventional cockpit on each of the 13 dimensions.

Table 18.

13 D CC-SART Dimension Ratings by Crew Station Configuration

<u>Dimension</u>	<u>Virtually-Augmented</u>	<u>Conventional</u>	<u>p < .1</u>
Level of Processing	3.49	3.83	ns
Naturalness	4.86	3.97	*
Automaticity	4.83	4.29	*
Association	4.58	4.21	*
Intuitiveness	4.88	4.07	*
Ease of Reasoning	5.4	4.83	*
Straightforwardness	5.5	4.94	*
Confusability	2.78	3.6	*
Understandability	5.53	4.97	*
Contradiction	2.67	3.06	*
Activation of Knowledge	5.75	5.4	*
Recognizability	5.81	5.58	ns
Familiarity	5.85	5.65	ns

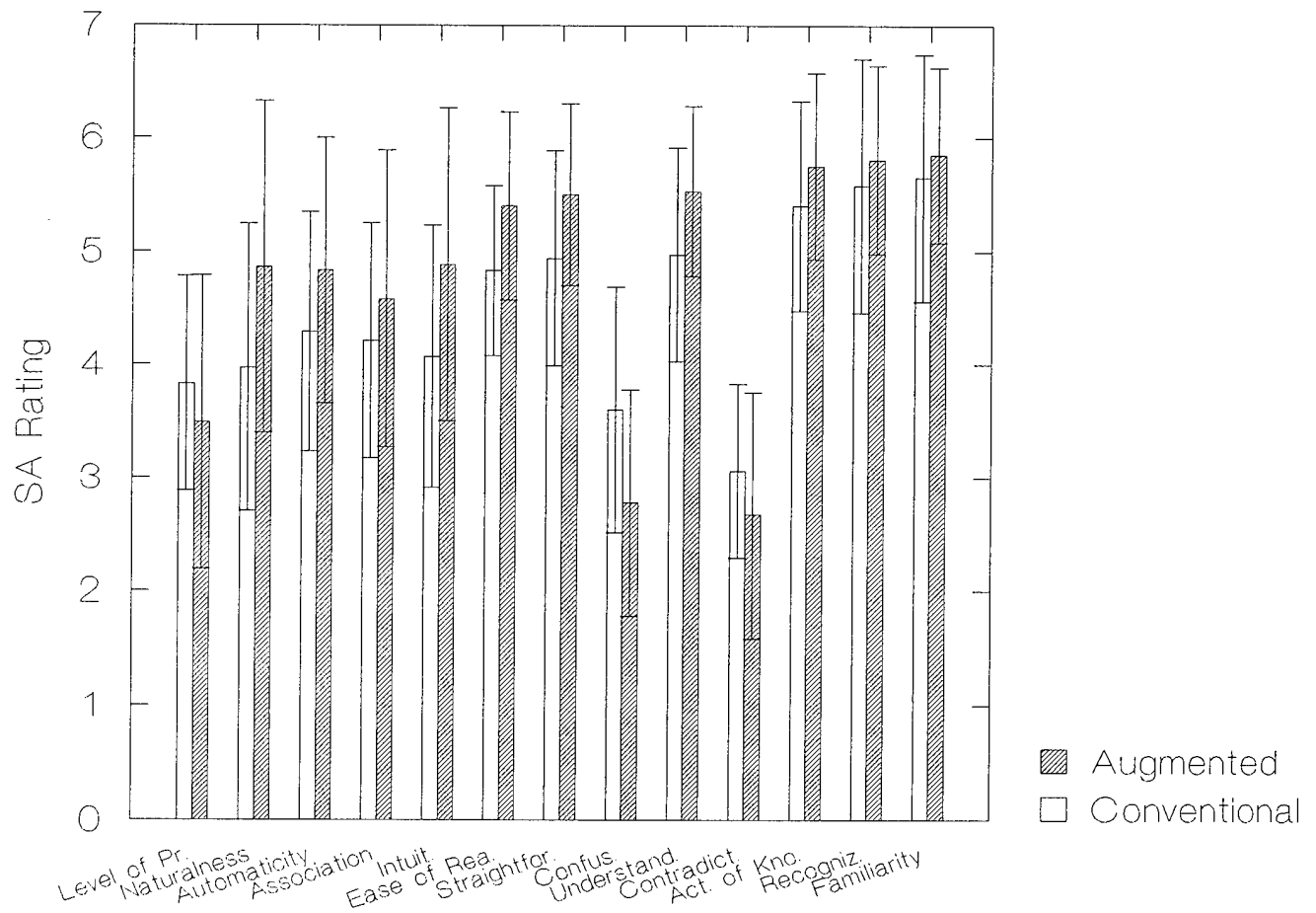


Figure 21. 13D CC-SART SA Ratings by Dimension and Crew Station Configuration.

5.4 Debrief Questionnaire

A 91-item debrief questionnaire was administered to all pilots following the final mission in the evaluation. Forty-six of these questions were quantitative in nature, requiring a numerical rating. A series of t-tests comparing the two crew station configurations were performed on these data. Out of these 46 questions, 22 yielded statistically significant differences ($p < .10$). In each case, the significant advantage was in favor of the virtually-augmented crew station. Of the 24 remaining questions, 16 yielded non-significant advantages for the virtually-augmented crew station while the other 8 yielded non-significant advantages for the conventional crew station.

Of the remaining 45 questionnaire items, 17 required pilots to indicate whether or not a particular event had occurred during the simulation (by answering "yes" or "no"). These items are summarized in section two of Appendix K. The remaining 28 items were designed to assess more qualitative issues regarding the simulation and the two primary crew station configurations. This section will present the results (in the form of means) of the quantitative questions for which statistically significant differences were observed, followed by a summary of pilots' responses to the qualitative items.

5.4.1 Statistically significant quantitative results

CAP Phase

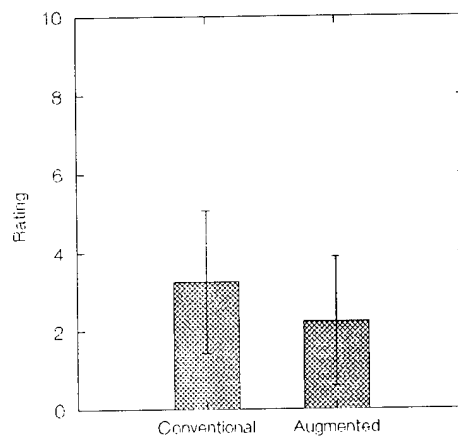
Questionnaire Item 1. *On a scale of 1-10, with 10 being "extremely difficult," how hard did you find the task of maintaining the prescribed CAP pattern?*

Virtually-Augmented

Conventional

2.24

3.24



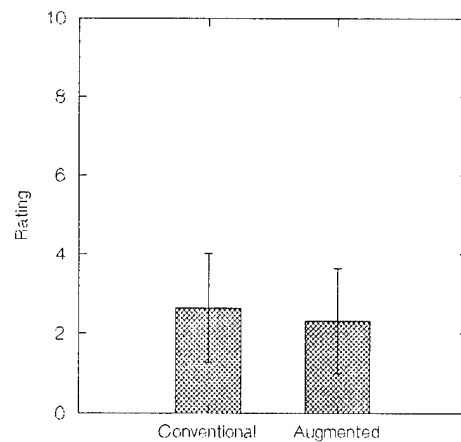
Questionnaire Item 7. *What do you estimate was your greatest deviation from the prescribed CAP pattern? (in NM).*

Virtually-Augmented

Conventional

2.32

2.65



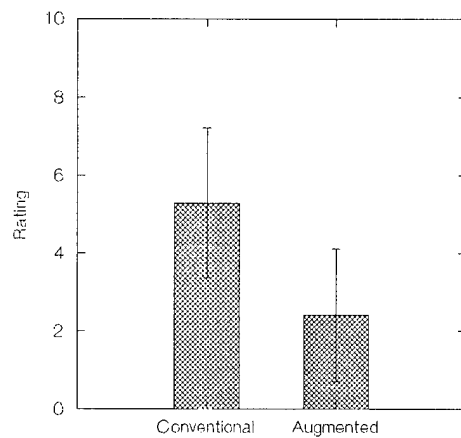
Questionnaire Item 12. *On a scale of 1-10, with 10 being "extremely difficult," how hard did you find the task of determining whether targets satisfied commit criteria?*

Virtually-Augmented

Conventional

2.14

5.29



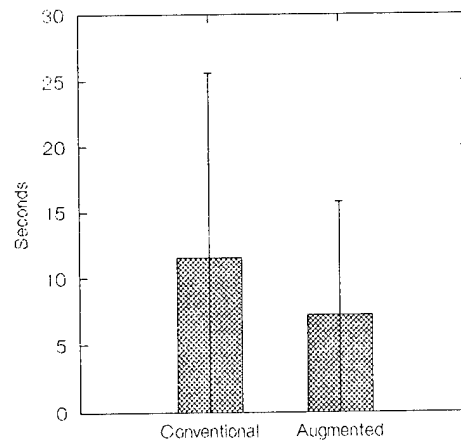
Questionnaire Item 13. *How long, on average, do you estimate it took to determine a target had met commit criteria, once that criteria had actually been met? (in seconds).*

Virtually-Augmented

Conventional

7.18

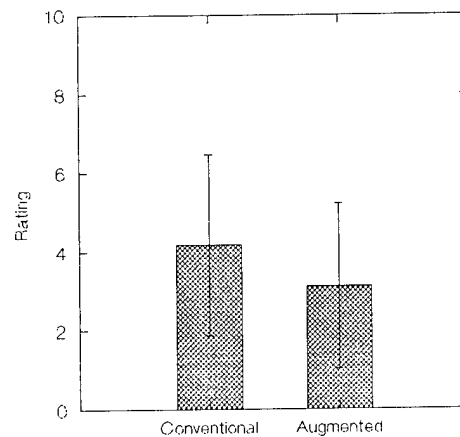
11.53



Intercept Phase

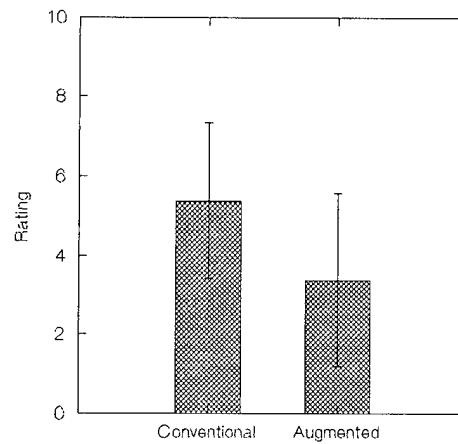
Questionnaire Item 23. *On a scale from 1 to 10, with 10 being "extremely difficult," how hard did you find the task of determining your position relative to a target during an intercept?*

Virtually-Augmented	Conventional
3.12	4.18



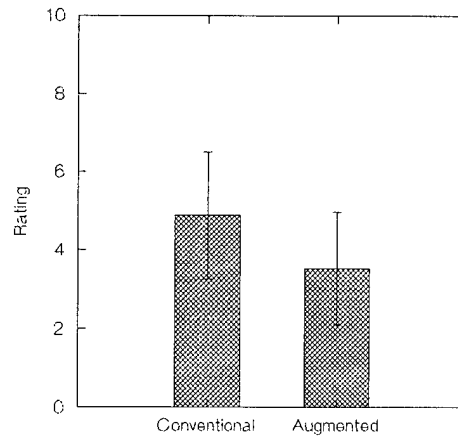
Questionnaire Item 24. *On a scale of 1-10, with 10 being "extremely difficult," how hard did you find the task of determining your threat from a target's weapon system during an intercept?*

Virtually-Augmented	Conventional
3.38	5.38



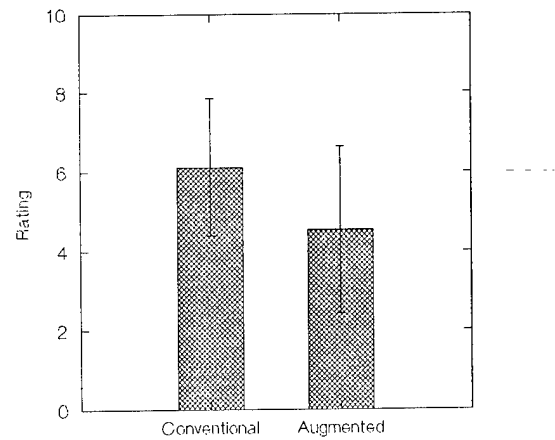
Question Item 26. *On a scale of 1-10, with 10 being “extremely difficult,” how hard did you find the task of determining your relative tactical advantage versus the target during intercept?*

Virtually-Augmented	Conventional
3.53	4.88



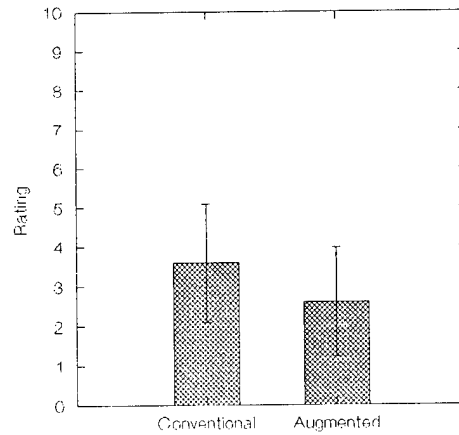
Questionnaire Item 27. *On a scale of 1-10, with 10 being “extremely difficult,” how hard did you find the task of determining your relative tactical advantage versus threats other than the primary target during an intercept?*

Virtually-Augmented	Conventional
4.53	6.12



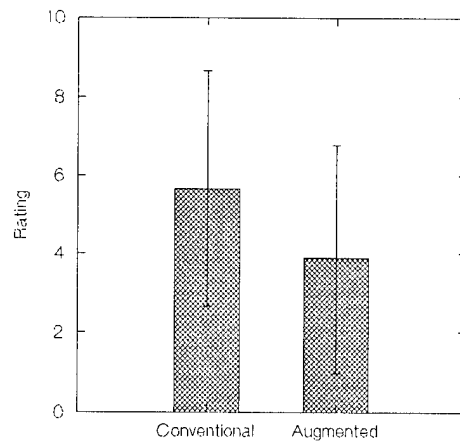
Questionnaire Item 30. *On a scale of 1 to 10, with 10 being "extremely difficult," how hard did you find the task of identifying friendly/hostile targets?*

Virtually-Augmented	Conventional
2.59	3.59



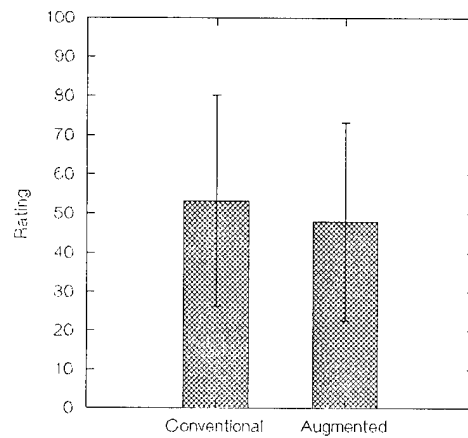
Questionnaire Item 34. *On a scale of 1 to 10, with 10 being "extremely difficult," how hard did you find the task of remaining within prescribed airspace while performing radar intercepts?*

Virtually-Augmented	Conventional
3.88	5.66



Questionnaire Item 37. *On a scale of 1 to 100, what percentage of your available attention do you estimate was allocated to the task of monitoring and controlling the radar while performing a radar intercept?*

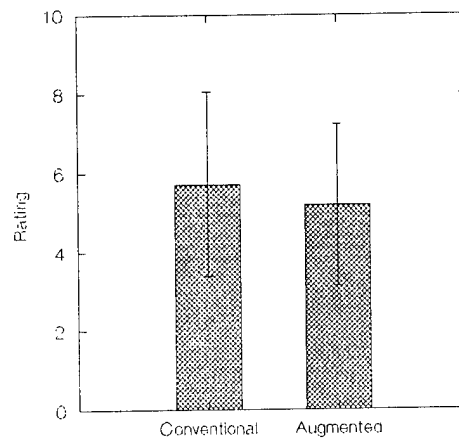
Virtually-Augmented	Conventional
47.94	53.24



Weapons Employment Phase

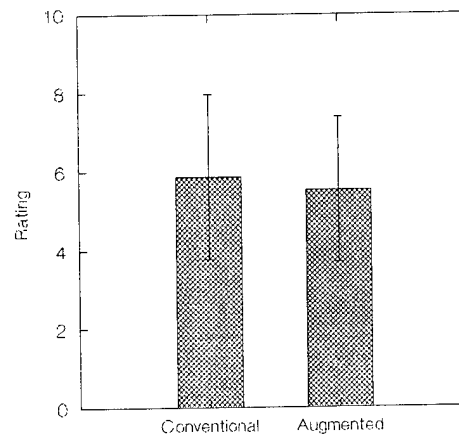
Questionnaire Item 46. *On a scale of 1 to 10, with 10 being "extremely difficult," how hard did you find the task of performing close-in combat in each configuration of the primary cockpit?*

Virtually-Augmented	Conventional
5.18	5.71



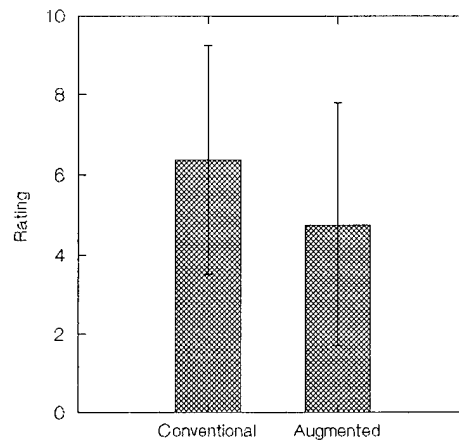
Questionnaire Item 47. *On a scale from 1 to 10, with 10 being “extremely difficult,” how hard did you find the task of determining your position relative to your primary opponents during close-in combat?*

Virtually-Augmented	Conventional
5.53	5.71



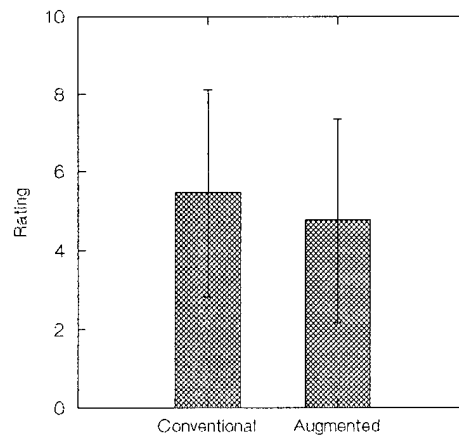
Questionnaire Item 48. *On a scale of 1 to 10, with 10 being “extremely difficult,” how hard did you find the task of determining your threat from an opponents weapon system during close in combat?*

Virtually-Augmented	Conventional
4.75	6.38



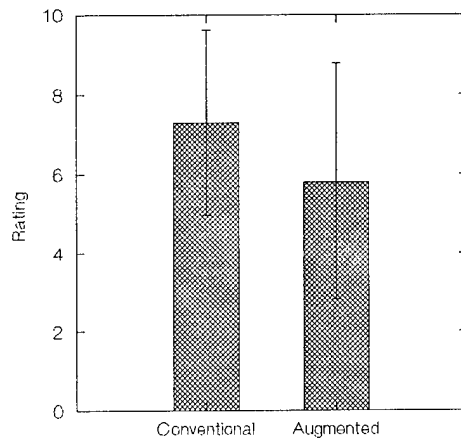
Questionnaire Item 50. *On a scale of 1 to 10, with 10 being "extremely difficult," how hard did you find the task of determining your relative tactical advantage versus your primary opponents during close in combat?*

Virtually-Augmented	Conventional
4.76	5.47



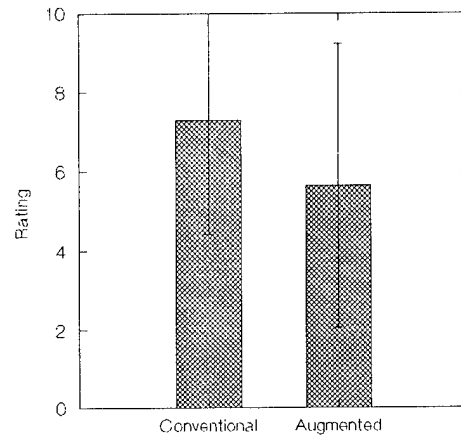
Questionnaire Item 51. *On a scale of 1 to 10, with 10 being "extremely difficult," how hard did you find the task of determining your relative tactical advantage versus threats other than your primary opponent during close-in combat?*

Virtually-Augmented	Conventional
5.8	7.3



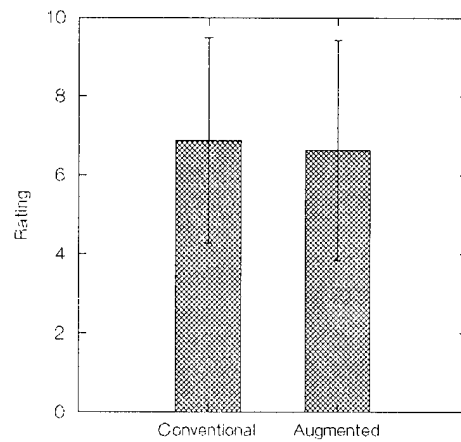
Questionnaire Item 54. *On a scale of 1 to 10, with 10 being “extremely difficult,” how hard did you find the task of remaining within prescribed airspace while performing close-in combat?*

Virtually-Augmented	Conventional
5.64	7.29



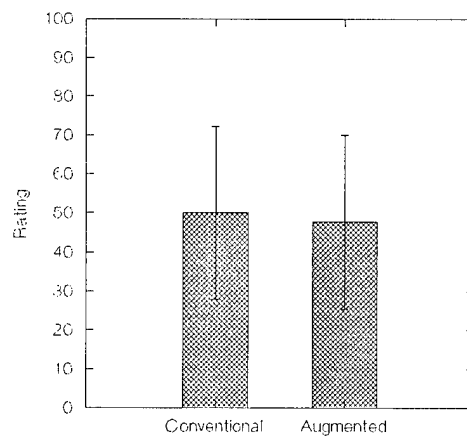
Questionnaire Item 56. *On a scale from 1 to 10, with 10 being “extremely difficult,” how hard did you find the task of maintaining desired maneuver conditions while performing close-in combat?*

Virtually-Augmented	Conventional
6.63	6.88



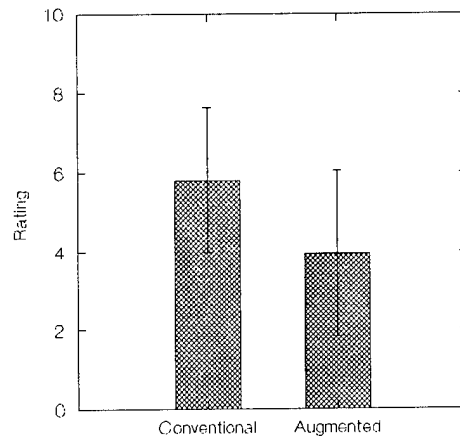
Questionnaire Item 58. *On a scale of 1 to 100, what percentage of your available attention do you estimate was allocated to the task of visually searching for targets while performing close-in combat?*

Virtually-Augmented	Conventional
47.79	50.09



Questionnaire Item 70. *On a scale of 1 to 10, with 10 being "extremely difficult," how hard did you find the task of determining the location, status, and threat of hostile aircraft?*

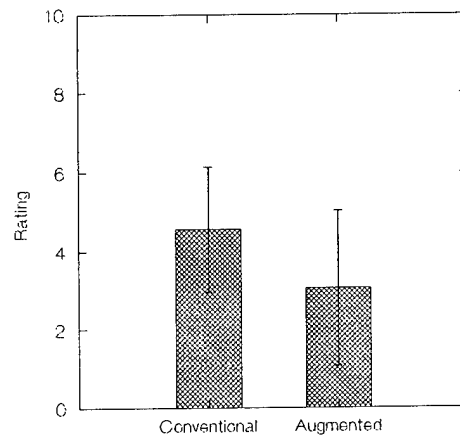
Virtually-Augmented	Conventional
3.94	5.81



Egress Phase

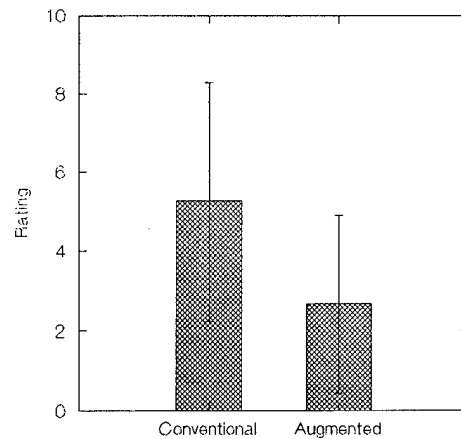
Questionnaire Item 81. *On a scale of 1 to 10, with 10 being "extremely difficult," how hard did you find the task of determining the threat level during egress?*

Virtually-Augmented	Conventional
3.06	4.56



Questionnaire Item 82. *On a scale from 1 to 10, with 10 being "extremely difficult," how hard did you find the task of remaining within prescribed airspace while performing an egress?*

Virtually-Augmented	Conventional
2.67	5.27



5.4.2 Non-significant quantitative results

Of the remaining 24 quantitative items, 16 yielded non-significant advantages for the virtually-augmented crew station over the conventional crew station. A selection of these results are presented below. Although there were no statistically significant differences between the two crew station configurations, these items are indicative of a generalized trend showing an advantage for the virtually-augmented crew station. Results for the remainder of the non-significant quantitative items may be found in Appendix K.

CAP Phase

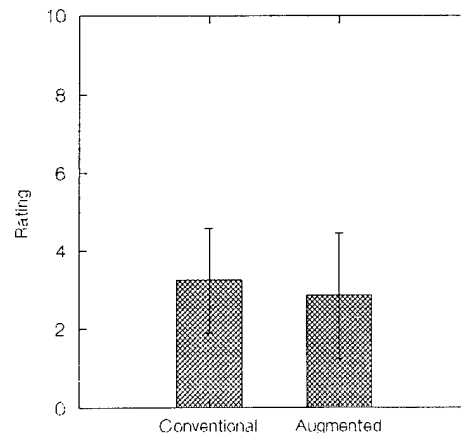
Questionnaire Item 19. *On a scale from 1 to 10, with 10 being "extremely difficult," how hard did you find the task of determining and controlling radar search volume while in the CAP pattern?*

Virtually-Augmented

Conventional

2.85

3.24



Intercept Phase

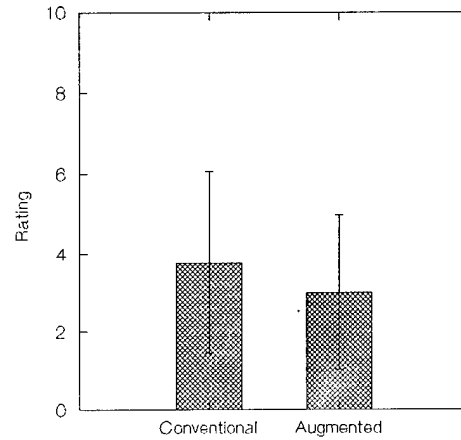
Questionnaire Item 22. *On a scale from 1 to 10, with 10 being “extremely difficult,” how hard did you find the task of performing a radar intercept to a desired point?*

Virtually-Augmented

Conventional

3

3.76



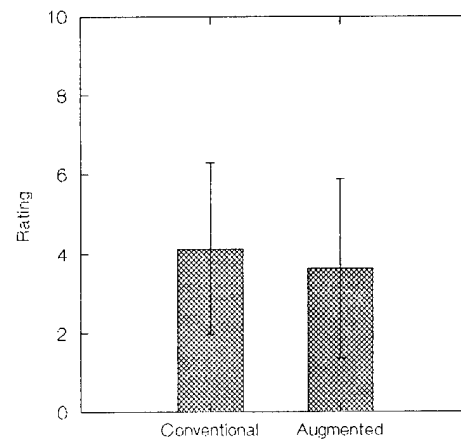
Questionnaire Item 25. *On a scale from 1 to 10, with 10 being “extremely difficult,” how hard did you find the task of determining the capability of your weapon system during an intercept?*

Virtually-Augmented

Conventional

3.63

4.13



Weapons Employment Phase

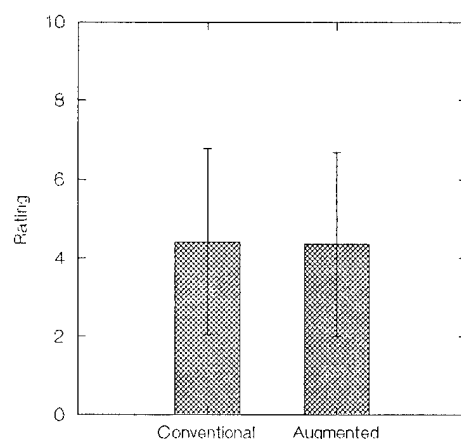
Questionnaire Item 49. *On a scale from 1 to 10, with 10 being "extremely difficult," how hard did you find the task of determining the capability of your weapons system during close-in combat?*

Virtually-Augmented

Conventional

4.35

4.41



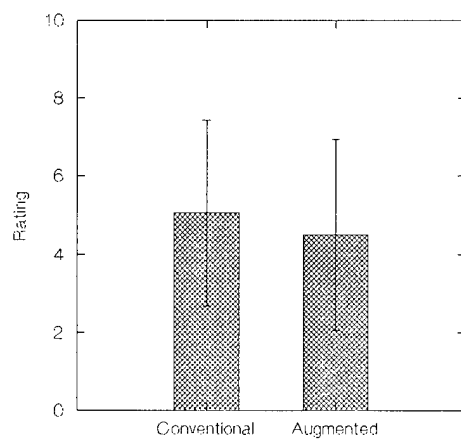
Questionnaire Item 65. *On a scale from 1 to 10, with 10 being "extremely difficult," how hard did you find the task of determining permissible and optimal weapons launch parameters?*

Virtually-Augmented

Conventional

4.5

5.06



5.4.3 Qualitative results

Of the remaining 45 questionnaire items, 28 required a qualitative, short answer response. Responses to these items may be found in section 1 of Appendix L. These responses revealed several major trends related to the pilot vehicle interface systems used in this study. In this section, the major trends will be addressed first, followed by a discussion of some of the difficulties reported by the pilots that were recognized limitations of the interfaces prior to the beginning of the evaluation.

1. *Ground-Collision Avoidance System.* There was nearly universal agreement among the pilots that the GCAS system in the virtually-augmented crew station configuration was well designed and extremely beneficial; indeed several of the pilots commented that the conventional crew station configuration should be equipped with a GCAS similar to that in the virtually-augmented crew station. The only negative comment regarding the GCAS system was that the “visual arrow” (part of GCAS indicating the direction to pull up to the pilot) displayed in the HUD was “too bright” on the display.

2. *Pictorial Format Color Display.* The use of color in the virtually-augmented crew station was regarded as a significant advantage, especially the color coding of hostile and friendly aircraft on the virtually-augmented tactical displays. The only negative comment regarding this system came from one pilot who pointed out that the various colors “might be less effective under weird lighting conditions.”

3. *ZOOM capability / Radar search scales.* A “zoom” feature was proposed as a potential improvement to the display of visual information. That is, a feature that would allow the pilot to “zoom-in to a close-up view of the enemy aircraft pack” was proposed as a feature that would allow the pilots to sort targets more rapidly while also providing for better resolution of the targets.

4. *Weapons Parameters Envelope.* The general consensus was that the weapons parameters displays should be changed, and there were many suggestions as to how this change should occur. The recommendations varied from a larger SHOOT or IN RANGE display readout, to a pictorial representation of one’s own weapons envelopes and those of the enemy. Several pilots requested that their weapons system automatically lock on to the first target that met commit criteria, with the pilot allowed to override this lock-on if necessary.

5. *Faster Target ID.* An improved target recognition/identification system was requested. Specific requests were made most often for an increased range capability, and a quicker ID response time.

6. *3-D sound/RWR system.* The 3-D sound capability of the RWR in the virtually-augmented crew station configuration was recognized as a significant improvement over the conventional crew station RWR configuration. This system was reported to be most effective during close-in combat and when used in conjunction with the GCAS system.

7. *VOICE warnings.* Although no voice warnings were incorporated into the current simulation system, many of the pilots reported the desirability of a voice-warning/voice display system. They requested a voice warning system to be used in conjunction with the GCAS system,

as a means of notifying pilots of a significant deviation from an optimal flight pattern, and as a warning system to alert the pilot to incoming missiles and/or nearby threats.

8. *Command Guidance.* Ground Controlled Intercept steering information was frequently requested as a steering cue to aid the interception of enemy aircraft. A second steering aid that was frequently requested was an autopilot to aid in maintaining the prescribed CAP pattern and intercept route.

9. *Elevation Display of Targets.* A display was requested that would present an "elevation" view, to include own-ship and targets, to aid during target intercept. Several pilots drew the display on the questionnaire form with range displayed on the x axis and altitude on the y axis.

10. *Expendables/ countermeasures.* The mechanism employed in this simulation for the deployment of chaff bundles and flares was an often criticized element of the simulation. Recommendations for improvement of this system included moving the selector switch from the sidestick to the throttle, and adding an auditory warning (e.g., tone or voice) when a chaff bundle or flare was deployed, rather than looking head down to ensure deployment.

11. *Helmet-mounted Display.* The HMD represented one area in which the pilots were divided. Some of the pilots thought that the HMD significantly improved their performance because it allowed them to lock targets without changing their flight path, and provided the ability to lock targets simply by looking at them. Alternatively, other pilots reported that the HMD should not include as much of the flight parameter data (e.g., altitude, airspeed, etc.) and that it was overly cluttered.

5.5 Limitations of the Simulation

Several limitations in the flight simulation system were addressed by the pilots in their responses to the debrief questionnaire. First, many of the pilots indicated that the "gaps" between the displays in the virtually-augmented model resulted in an increase in effort and that they were "distracting," and "inhibited target sort performance," especially at longer ranges. This limitation in the simulation was known prior to the evaluation. The virtually-augmented crew station configuration was designed to be presented on a single display surface, rather than on six individual panels. However, display panels large enough to accommodate the virtually-augmented format are not available at this time.

A second difficulty resulting from the gap between the screens involved interference with the use of the radar designator cursor. Since the simulation hardware required the use of "virtual buttons" (e.g., displayed buttons actuated by placing the cursor over them and then depressing a real button or switch on the control stick or throttle), accurate positioning of the cursor was critical. As with the previously mentioned shortcoming, the solution to the problem of gaps between the displays awaits the development of larger displays.

Finally, several of the pilots indicated that the task was more difficult due to a poor OTW display system. In addition, several of the pilots remarked that missile defense maneuvers were nearly impossible to time correctly due to the impoverished OTW display and the inability to "see" the enemy missiles in flight.

6.0 DISCUSSION

The results of this evaluation revealed a number of significant advantages for the virtually-augmented crew station among a number of operationally relevant performance metrics. As depicted in Figure 22, the use of the virtually-augmented crew station resulted in superior performance in terms of wins, threats killed, exchange ratio, ground strikes, and mission length. In addition, workload and SA assessment techniques (SWORD, CC-SART, and 13-D CC-SART) revealed consistent advantages for the virtually-augmented crew station. These findings indicate that this new design not only results in superior mission performance, but does so at the cost of less workload and enhanced SA. It is important to note that each of these statistically significant advantages for the virtually-augmented crew station were obtained despite the absence of previous experience with these displays. Comparatively, the pilots who participated in this evaluation had hundreds of hours of flight experience using the conventional crew station.

The results of the debrief questionnaire indicated that pilots' improved performance with the virtually-augmented crew station was accompanied by generally positive subjective responses to its characteristics and features. As illustrated in Color Plate 7, the majority of quantitative responses to the questionnaire produced findings that were favorable toward the new design. Several of the questionnaire items offer some insight into how specific display innovations positively impacted on performance of the air combat task. For instance, the large difference noted between the two crew station configurations in terms of their ability to specify whether or not targets met commit criteria is depicted in questionnaire items 12 and 13. In a similar fashion, the greater ability of the virtually-augmented cockpit to specify ownship location relative to the target is reflected in questionnaire item 23. In general, those aspects of the mission that relied on target identification, and maintenance of tactical position relative to the target, appeared to be most positively affected by the virtually-augmented crew station design. In addition, the GCAS system was effective in preventing the occurrence of catastrophic ground strikes and was also enthusiastically endorsed by the pilots in their debrief remarks and evaluations. The pictorial format display and the color coding of friendly and enemy aircraft also received highly favorable ratings. Finally, the use of three dimensional audio cueing for the radar warning receiver was also highly accepted.

In spite of the widespread acceptance and favorable ratings of the virtually-augmented crew station found in this study, along with the previously described performance, SA, and workload advantages, pilots did indicate some perceived limitations with the virtually-augmented crew station. First, the pilots disliked the spatial separations in the display panel surface. Although these breaks were necessary due to simulation hardware constraints, the pilots found the panel breaks to be intrusive to the performance of the mission, and inhibited target sort performance. This was a recognized limitation of the simulation hardware prior to the onset of the evaluation. The virtually-augmented crew station interface was designed to be displayed on a single large-panel display. Therefore, although the pilots rated the panel breaks as troublesome in the current implementation, the panel breaks would not be present in an operational interface as specified in the virtually-augmented crew station display design.

In addition to the panel breaks, the pilots also found the radar designator cursor and the use of virtual buttons in the virtually-augmented crew station to be problematic. The cursor was thought to be too sensitive, thus sometimes difficult to use. This limitation was easily fixed and a modified version of display interaction will be implemented and tested in future interface evaluations.

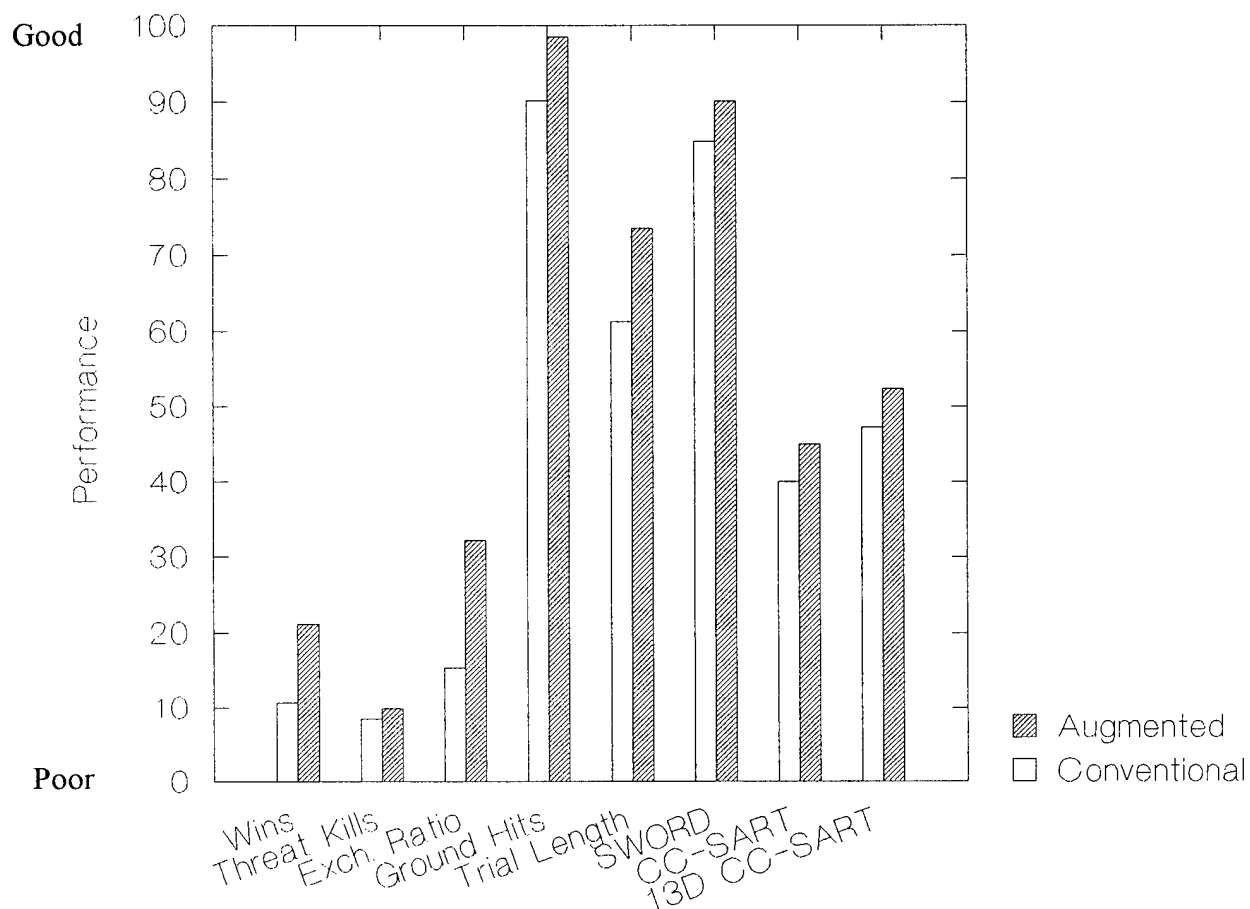
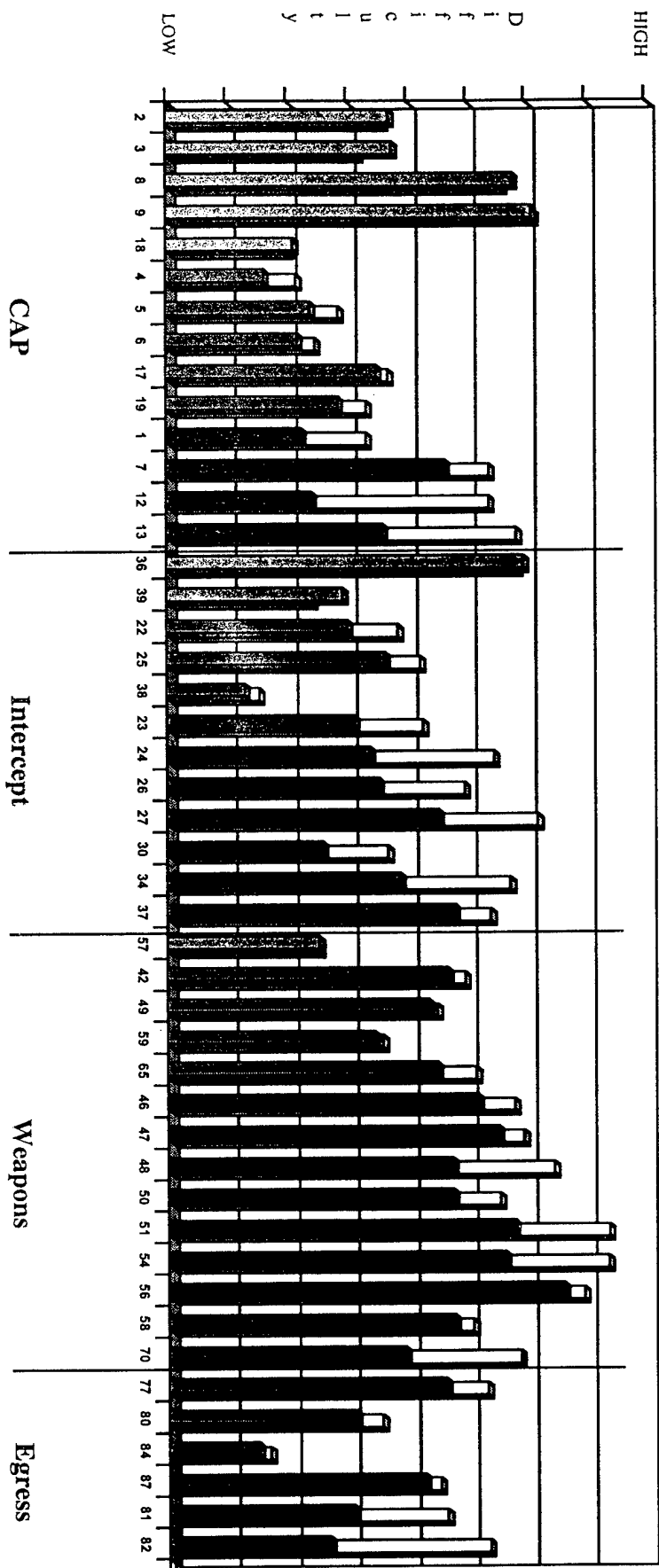


Figure 22. Results Summary

Note: The figure depicts normalized, non-dimensional trends across several dependent variables including pilot-aircraft system output measures, workload measures, and situation awareness measures. Refer to the text for details specific to each of the variables presented.

Debrief Summary

■ Virtually - Augmented
 □ Conventional



Conventional Cockpit Advantage - ns
 Virtually-Augmented Cockpit Advantage - ns
 Virtually-Augmented Cockpit Advantage * $p < .1$

Color Plate 7. Debrief Summary

Our future work in this area will be geared toward the development of interface concepts whose design will take advantage of the positive aspects of the displays and controls identified in this evaluation. In addition, we will attempt to improve upon those features that did not appear to significantly improve performance. We propose to approach this work by forming a variety of "design teams" from the following groups: Experienced fighter pilots with an interest in crew station design issues, academic researchers with expertise in the human factors and ergonomics of multisensory display design, and interface developers from private industry. Our goal in our next interface evaluation is to integrate display and control concepts from these design teams, and evaluate their ability to support the performance of a simulated air-to-ground combat task.

7.0 REFERENCES

- Adam, E. (1994). Tactical cockpits: The coming revolution. In R.D. Gilson, D.J. Garland, & J.M. Koonce (Eds.), Situation Awareness in Complex Systems: Proceedings of a CAHFA Conference, (p. 101-110). Daytona Beach, FL: Embry-Riddle Aeronautical University Press.
- Arbak, C., King, P. Jauer, R., & Adam, E. (1988). Helmet-Mounted Display/Sight Tactical Utility Study (Report No. AAMRL-TR-88-022). Harry G. Armstrong Aerospace Medical Research Laboratory, Human Systems Division, Wright-Patterson AFB, OH.
- Beal, C., & Sweetman, B. (1994). Helmet mounted displays: Are we jumping the gun? International Defense Review, 27, 69-75.
- Beringer, D.B., Allen, R.C., Kozak, K.K., & Young, G.E. (1993). Responses of pilots and nonpilots to color-coded altitude information in a cockpit display of traffic information. In Proceedings of the Human Factors and Ergonomics Society 37th Annual Meeting, (pp. 4-87). Santa Monica, CA: Human Factors and Ergonomics Society.
- Brickman, B.J., Hettinger, L.J., Roe, M.M., Lu, L., Repperger, D.W., & Haas, M.W. (1996). Haptic specification of environmental events: Implications for the design of adaptive, virtual interfaces. In Proceedings of IEEE Virtual Reality Annual Symposium, (pp. 147-153). Los Alamitos, CA: IEEE Computer Society Press.
- Brickman, B.J., Hettinger, L.J., Roe, M.M., Stautberg, D., Vidulich, M.A., Haas, M.W., & Shaw, R.L. (1995). An assessment of situation awareness in an air combat simulation: The global implicit measure approach. In D.J. Garland, & M.R. Endsley (Eds.), Experimental Analysis and Measurement of Situation Awareness: Proceedings of an International Conference, (pp. 339-344). Daytona Beach, FL: Embry-Riddle Aeronautical University Press.
- Calhoun, G.L., Valencia, G., & Furness, T. (1987). Three-dimensional auditory cue simulation for crew station design/evaluation. In Proceedings of the Human Factors Society 30th Annual Meeting (pp. 1398-1402). Santa Monica, CA: Human Factors Society.
- Cress, J.D., Hettinger, L.J., Cunningham, J.A., Riccio, G.E., McMillan, G.R.M., & Haas, M.W. (1996). An initial evaluation of a direct vestibular display in a virtual environment. In Proceedings of the Human Factors and Ergonomics Society 49th Annual Meeting, Vol. 2, (pp. 1131-1135). Santa Monica, CA: Human Factors and Ergonomics Society.
- Cunningham, J.A., Nelson, W.T., Hettinger, L.J., Russell, C., & Haas, M.W. (1995). Assessing target detection performance using head position data: A qualitative and quantitative analysis. In Proceedings of the 8th International Symposium on Aviation Psychology, Vol. 1, (pp. 158-163). Columbus, OH: Ohio State University.

- DeVilbiss, C.A., & Sipes, W.E. (1995). Effect of arc segmented attitude reference symbology on a helmet-mounted display during an unusual attitude recovery task. In Proceedings of SPIE Volume 2465: Helmet and Head Mounted Displays and Symbology Design Requirements II Conference (pp. 255-262). Orlando, FL: SPIE-The Society for Optical Engineering, April, 1995.
- Dornheim, M.A. (Oct. 23, 1995a). U.S. Fighters to get helmet displays after 2000. Aviation Week & Space Technology, 46-47.
- Dornheim, M.A. (Oct. 23, 1995b). Test programs prepare for helmet production. Aviation Week & Space Technology, 52-54.
- Dornheim, M.A., & Hughes, D. (Oct. 16, 1995). U.S. intensifies efforts to meet missile threat. Aviation Week & Space Technology, 36-39.
- Ellis, S.R., McGreevy, M.W., & Hitchcock, R.J. (1987). Perspective traffic display format and airline pilot traffic avoidance. Human Factors, 29, 371-382.
- Endsley, M.R. (1990). A methodology for the objective measurement of pilot situation awareness. In AGARD-CP-478, Situational awareness in aerospace operations (pp. 1-1 - 1-9). Neuilly Sur Seine, France: Advisory Group for Aerospace Research and Development. (AD-A223939).
- Ericson, M., McKinley, R., Kibbe, M. & Francis, D. (1994). Laboratory and in-flight experiments to evaluate 3-D audio display technology. Seventh Annual Workshop on Space Operations Applications and Research (Vol II., pp. 371-377). Johnson Space Center, TX.
- Foster, S.H. (1988). Convolvotron (tm) User's Manual. Crystal River Engineering, Groveland, CA.
- Furness, T. A. III. (1986). The super cockpit and its human factors challenges. In Proceedings of the Human Factors Society 30th Annual Meeting (pp. 48-52). Santa Monica, CA: Human Factors Society.
- Gehring, B. (1990). Focal Point (tm) 3D Sound User's Manual. Gehring Research Corporation, Toronto, Canada.
- Haas, M.W. (1992). Multi-sensory virtual-interface technology. In Proceedings of the 25th Annual NATO Defence Research Group Seminar: The Future Battlefield. Imperial College of Science and Technology, London, England.
- Haas, M.W., & Hettinger, L.J. (1993). Applying virtual reality technology to cockpits of future fighter aircraft. Virtual Reality Systems, 1(2), 18-26.
- Haas, M.W., Hettinger, L.J., Nelson, W.T., & Shaw, R.L., (1995). Developing virtual interfaces for use in future fighter aircraft cockpits (Report No. AL/CF-TR-1995-0154). Wright-Patterson AFB, OH: Armstrong Laboratory.

- Hettinger, L.J., Cress, J.D., Brickman, B.J., & Haas, M.W. (1996). Adaptive interfaces for advanced airborne crew stations. In Proceedings of the 3rd Annual Symposium on Human Interaction with Complex Systems, (pp. 188-192). Los Alamitos, CA: IEEE Computer Society Press.
- Hettinger, L.J., Nelson, W.T., & Haas, M.W. (1994). Applying virtual environment technology to the design of fighter aircraft cockpits: Pilot performance and situation awareness in a simulated air combat task. In Proceedings of the 1994 Human Factors and Ergonomics Society Meeting, (pp. 115-118), Santa Monica, CA: Human Factors and Ergonomics Society.
- Hopper, D.G. (1992). Panoramic cockpit displays. In AGARD-CP-521, Advanced Aircraft Interfaces: The Machine Side of the Man Machine Interface (pp. 9-1 - 9-24). Neuilly Sur Seine, France: Advisory Group for Aerospace Research and Development Avionics Panel.
- Hughes, D. (Oct. 16, 1995). Luftwaffe MiG pilots effective with ARCHER. Aviation Week & Space Technology, 39.
- Ineson, J. (1994). The DRA virtual cockpit research programme. In AGARD-CP-541, Virtual Interfaces: Research and Applications (pp. 8-1 - 8-7). Neuilly Sur Seine, France: Advisory Group for Aerospace Research and Development.
- Kubovy, M. (1981). Concurrent pitch-segregation and the theory of indispensable attributes. In M. Kubovy & J.R. Pomerantz (Eds.), Perceptual organization (pp. 55-98), Hillsdale, NJ: Lawrence Erlbaum.
- Liggett, K.K., Benson, M.J., Solz, T.J., & Reising, J.M. (1995). An examination of cursor techniques to designate targets on a cockpit map display. In Proceedings of SPIE Volume 2462: Cockpit Displays II (pp. 27-35). Orlando, FL: SPIE-The Society for Optical Engineering, April, 1995.
- Liggett, K.K., Reising, J.M., & Hartsock, D.C. (1992). The use of a background attitude indicator to recover from unusual attitudes. In Proceedings of the Human Factors Society 36th Annual Meeting (pp. 43-47). Santa Monica, CA: Human Factors Society.
- Liggett, K.K., Reising, J.M., Solz, T.J., & Hartsock, D.C. (1996). A comparison of military electronic approach plate formats. In Proceedings of the Human Factors and Ergonomics Society 40th Annual Meeting (pp. 15-19). Santa Monica, CA: Human Factors and Ergonomics Society.
- McKinley, R.L., D'Angelo, W.R., Haas, M.W., Perrott, D.R., Nelson, W.T., Hettinger, L.J. & Brickman, B.J. (1995). An initial study of the effects of 3-dimensional auditory cueing on visual target detection. In Proceedings of the Human Factors and Ergonomics Society 39th Annual Meeting, (pp. 119-123). Santa Monica, CA: Human Factors and Ergonomics Society.

MIL-STD-1787 - Military Standard Aircraft Display Symbolology.

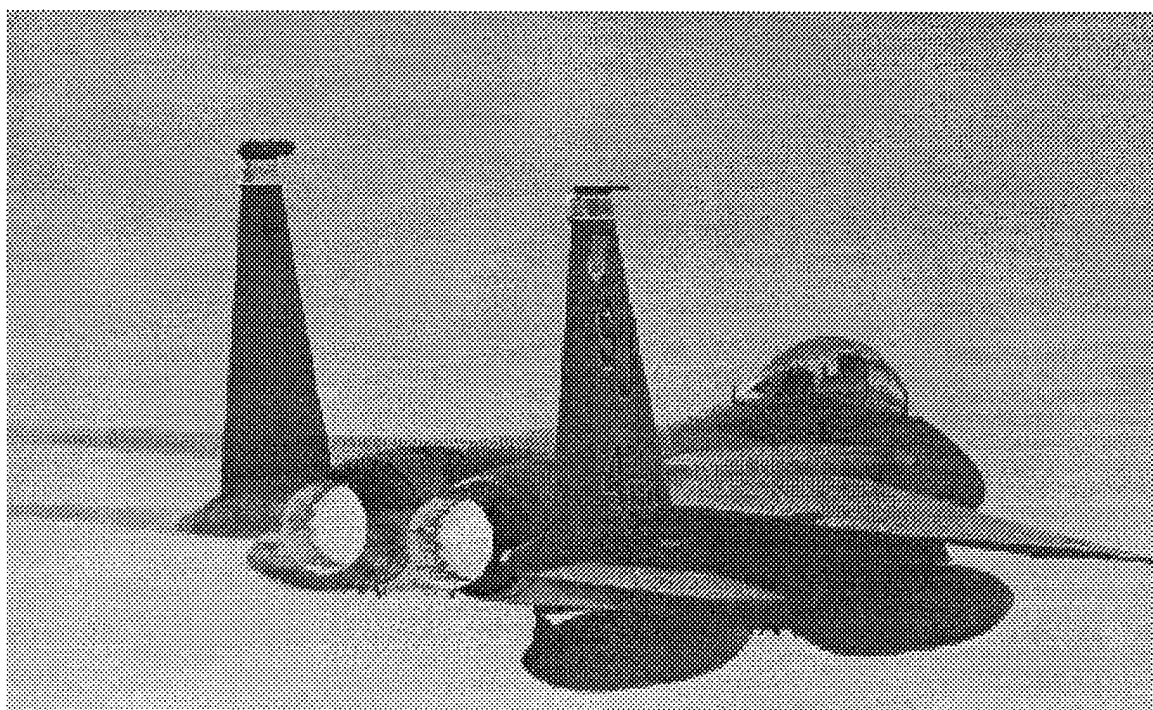
- Mykityshyn, M.G., & Hansman, R.J. (1991). Development and evaluation of prototype designs for electronic display of instrument approach information (Tech. Report DTRS-57-88-C-00078). Cambridge, MA: Massachusetts Institute of Technology.
- Mykityshyn, M.G., Kuchar, J.K., & Hansman, R.J. (1994). Experimental study of electronically based instrument approach plates. International Journal of Aviation Psychology, 4(2), 141-146.
- Mowbray, G.H. & Gebhard, J.W. (1961). Man's senses as information channels. In H.W. Sinaiko (Ed.), Human factors in the design and use of control systems (pp. 115-149). New York: Dover.
- National Research Council (1995). Virtual reality: Scientific and technical challenges. Washington, DC: National Academy Press.
- Nelson, W.T., Hettinger, L.J., Cunningham, J.A., Roe, M.M., Lu, L., Haas, M.W., Dennis, L.B., Pick, H.L., Junker, A., & Berg, C.B. (1996). Brain-body actuated control: Assessment of an alternative control technology for virtual environments. In Proceedings of the 1996 IMAGE Conference, (pp. 225-232). Chandler, AZ: IMAGE Society.
- Nelson, W.T., Hettinger, L.J., Haas, M.W., Russell, C., Warm, J.S., Dember, W.N., & Stoffregen, T.A. (1995). Compensation for effects of time delay in a helmet-mounted display: Perceptual adaptation versus algorithmic prediction. In SPIE Proceedings on Helmet- and Head-Mounted Displays and Symbolology Design Requirements II, Orlando, FL.
- Olson, J.L., Arbak, C.J., & Jauer, R.A. (1991). Panoramic Cockpit Control and Display System: Volume II. PCCADS 2000 (Report No. AL-TR-91-0017). Visual Displays Research Branch, Human Engineering Division, Armstrong Laboratory, Wright-Patterson AFB, OH.
- Patterson, R.R. (1982). Guidelines for auditory warning systems on civil aircraft. (Paper No. 82017), London: Civil Aviation Authority.
- Reid, G. B., Potter, S. S., Bressler, J. R. (1989). Subjective workload assessment technique (SWAT): A users guide (U). AAMRL-TR-89-023.
- Reising, J.M., & Emerson, T.J. (1982). Color display formats: A revolution in cockpit design. In AGARD CP 329, Advanced Avionics and the Military Aircraft Man/Machine Interface (pp. 6-1 - 6-11). Neuilly Sur Seine, France: Advisory Group for Aerospace Research & Development.
- Selcon, S.J., Taylor, R.M., & Shadrake, R.A. (1992). Multi-modal cockpit warnings: Pictures, words, or both? In Proceedings of the Human Factors Society 36th Annual Meeting (pp. 57-61). Santa Monica, CA: Human Factors Society.
- Stokes, A. F., Wickens, C.D., & Kite, K. (1990). Display Technology: Human Factors Concepts. Warrendale, PA: Society of Automotive Engineers.

- Taylor, R.M. (1990, April) Situational awareness rating technique (SART): The development of a tool for aircrew systems design. In AGARD CP 478, Situational Awareness in Aerospace Operations (pp. 3 1 to 3 17). Neuilly Sur Seine, France: Advisory Group for Aerospace Research & Development. (AD A223939).
- Taylor, R.M. (1995). CC-SART: The development of an experimental measure of cognitive compatibility in system design. Report to TTCP UTP-7 Human Factors in Aircraft Environments, Annual Meeting, DCIEM, Toronto, Canada, 12-16 June.
- Tripp, L.D., Hettinger, L.J., Haas, M.W., Nelson, W.T., & Wilson, G. (1995). Cerebral blood flow velocity during flight simulation as measured using transcranial doppler (Abstract). In Proceedings of the Aerospace Medical Association 65th Annual Scientific Meeting, Anaheim, CA, May, 1995
- Vidulich, M. A., Ward, F. G., Schueren, J. (1991). Using the subjective workload dominance (SWORD) technique for projective workload assessment. Human Factors, 33, 677-691.
- Voulgaris, T., Metalis, S., & Mobley, S. (1995). An integrated primary flight display: The Sky Arc. In SPIE Proceedings on Helmet- and Head-Mounted Displays and Symbology Design Requirements II, Orlando, FL.
- Weinstein, L.F., Gillingham, K.K., & Ercoline, W.R. (1994). United States Air Force head-up display control and performance symbology evaluations. Aviation Space & Environmental Medicine, 65(5) Section 2, A20-A30.
- Wenzel, E.M. (1992). Localization in virtual acoustic displays. Presence, 1, 80-107.



F.I.T.E.

Fusion Interfaces for Tactical Environments Laboratory 1995 RULES OF ENGAGEMENT



FITE LAB

RULES OF ENGAGEMENT

TRAINING MANUAL

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List of Acronyms

A

AAA	Anti-Aircraft Artillery
AAM	Air to Air Missile
ADI	Attitude Direction Indicator
AGL	Above Ground Level Altitude
AMRAAM	Advanced Medium Range Air to Air Missile
AOA	Angle of Attack
ASE	Allowable Steering Error

B

BST	Boresight Mode
-----	----------------

C

CAP	Combat Air Patrol
CDI	Course Deviation Indicator
CIC	Close In Combat

D

DEG	Degrees
-----	---------

E

F

FITE	Fusion Interfaces for Tactical Environments Laboratory
FOV	Field Of View
FPM	Feet Per Minute

G

GCAS	Ground Collision Avoidance System
------	-----------------------------------

H

HDD	Head Down Display
HMD	Helmet Mounted Display
HOTAS	Hands On Throttle And Stick
HSI	Horizontal Situation Indicator
HUD	Head Up Display

I

IR	Infra Red
----	-----------

Appendix A. (continued).

J

K

KCAS	Knots Calibrated Air Speed
KIAS	Knots Indicated Air Speed
KTAS	Knots True Air Speed

L

LCD	Liquid Crystal Display
LCOS	Lead Computing Optical Sight
LOS	Line Of Sight

M

MRM	Medium Range Missile
MSL	Mean altitude above Sea Level

N

NM	Nautical Mile
----	---------------

O

OTW	Out The Window display
-----	------------------------

P

PD	Pulse-Doppler
PDT	Primary Designated Target
POM	Plane Of Maneuver

Q

R

RWR	Radar Warning Receiver
RWS	Range While Search

S

SA	Situation Awareness
SAM	Surface to Air Missile
SRM	Short Range Missile
SSI	Systems Status Indicator
SSL	Slewable Scan Lock
STT	Single Target Track

Appendix A. (continued).

T

TAA	Target Aspect Angle
TAS	True Air Speed
TD	Target Designator
TDI	Target Direction Indicator
TID	Target Identification System
TTA	Time To Active
TTG	Time To Go
TWS	Track While Scan

U

V

VSD	Vertical Situation Display
VSL	Vertical Scan Lock

W

X

Y

Z

1.0 RULES OF ENGAGEMENT

In an effort to evaluate and quantify pilot situation awareness (SA) on a continuous basis during simulated air-to-air combat missions in the Fusion Interfaces for Tactical Environments (FITE) Lab, pilot responses to the tactical situation will be closely monitored. In order to evaluate the appropriateness of pilot actions, it is desirable to constrain the actions of the subject relative to the tactical situation. Analysts can then be relatively certain of what the pilot subject INTENDS to do under given tactical conditions. The subjects' actions may then be related directly to their SA of the tactical situation. Therefore, guidelines are provided here to instruct subject pilots on their required actions.

It is recognized that the constraints listed here are more limiting than would be typical in an actual tactical environment, and may not, in all cases, provide an optimal tactical solution to a given situation. The subject pilots should be aware that performance in these exercises will be rated based on compliance with the rules stated here, rather than the more usual measures of success, like enemy aircraft destroyed, survival rate, etc.

Rules of Engagement (ROE) are organized by mission phase, and include a target/goal for pilot performance in various areas, as well as procedures to follow when making corrections toward the stated goal.

1.1 Combat Air Patrol (CAP)/Target Search Phase

The goal of the CAP/Target Search Phase is to detect hostile aircraft as early as possible and to "commit" to intercept hostile targets as quickly as possible after they penetrate the boundaries of the assigned threat sector. This phase ends the first time either of the "Commit Criteria" below are met:

- A hostile bomber is detected inside the boundaries of the assigned threat sector or friendly airspace;
- A hostile fighter with a target aspect angle (TAA) equal to, or exceeding 120 deg is detected inside the boundaries of the assigned threat sector or friendly airspace.

As soon as Commit Criteria are met the pilot should announce "Commit," with the offending target's class (i.e., fighter/bomber) and position (bearing and range) relative to "Bullseye." For instance, "Commit, bomber, 350/40." For purposes of defining the Commit Point, if any UNKNOWN member of a formation of radar contacts meets Commit Criteria, and any other member of the same formation is identified as HOSTILE, then Commit Criteria are considered to have been satisfied.

Course control:

Conventional Cockpit - Track outbound from the CAP point (20 DME from "Homeplate") on the 360-deg radial until reaching 10 NM (nautical miles) North of the fix (30 DME). Make a left turn at the fix to intercept an inbound leg defined by the Course Deviation Indicator (CDI) needle on the Horizontal Situation Indicator (HSI) positioned one dot to the East. Begin a left turn to the outbound leg at 20 DME, intercepting the 360-deg radial to complete the racetrack CAP pattern. Adjust the inbound/outbound turns as required to intercept the specified legs of the CAP pattern. Make positive course corrections to maintain/regain the prescribed pattern as closely as possible.

Candidate Cockpit - Maintain the racetrack CAP pattern depicted on the Head-Down Display (HDD).

Both Cockpits - In order to determine a more accurate Commit time, the outbound turn of the CAP pattern may be cut short or the outbound leg may be extended so that radar coverage can be provided at the moment of commit criteria are met.

Appendix A. (continued).

- Begin the outbound turn early if Commit Criteria are predicted (based on current or previous radar contacts) to be met prior to reaching the prescribed inbound limit (20 DME) of the CAP pattern;
- When "UNKNOWN" radar contacts are detected inside the designated threat sector, the inbound turn may be delayed or curtailed as necessary ("float") in order to maintain radar coverage of the contact until the target is identified. In this case, select a course that minimizes deviation from the prescribed CAP pattern while allowing radar coverage to be maintained.

Airspeed control:

Conventional Cockpit - Maintain 412 KIAS while in the CAP Phase.

Candidate Cockpit - Maintain corner speed, as indicated by the double tick mark on the Head-Up Display (HUD) and Helmet Mounted Display (HMD) airspeed indicators.

Both Cockpits - Make positive airspeed corrections with the throttle to maintain/regain target airspeed.

Altitude control:

Maintain 15,000 MSL (altitude above mean sea level, ft) while in the CAP Phase. Make altitude corrections at any desired rate while maintaining target airspeed.

Radar mode control:

Remain in Track-While-Scan (TWS) mode when in the CAP Phase.

Radar range select:

Select the minimum radar range scale that provides coverage of the outer limit of the threat sector.

Radar azimuth limit control:

Select the minimum azimuth limit that provides full azimuth coverage of the threat sector at its outer limit.

Radar azimuth center control:

Center the radar search azimuth when established on the outbound leg of the CAP pattern. When established on the inbound leg of the pattern, adjust radar azimuth to provide coverage 60 deg left of the nose for earliest coverage of the threat sector during the outbound turn. Note: this will not require any pilot action if +/- 60-deg azimuth limits are selected. Adjust azimuth center as necessary to provide maximum coverage of the outer limits of the threat sector while intercepting the outbound leg of the CAP pattern.

Radar elevation bar control:

Select the minimum elevation bars that provide coverage from the surface (2,000 MSL) to at least 50,000 MSL at the outer limit of the threat sector.

Appendix A. (continued).

Radar elevation (Thumbwheel) control:

- Prior to Target Detection - Adjust the radar elevation so as to provide coverage of the surface (2,000 MSL) at a point 10 NM inside the outer limits of the threat sector.
- After Target Detection - Adjust the radar elevation so that the maximum number of detected hostile and unidentified targets remain covered.

Primary designated target (PDT) control:

- Maintain as PDT the nearest target not identified as “friendly” while in the CAP Phase.
- Note: Do not establish a Single-Target Track (STT) while in the CAP Phase.

Weapons selection:

Medium-Range Missiles (MRM) should be selected when in the CAP Phase.

1.2 Intercept /Attack Phase

The Intercept Phase begins with the Commit announcement and ends when all the hostile bombers have been destroyed, all weapons (including gun ammo) has been expended, or JOKER fuel state is reached. The target designated in the Commit announcement becomes the “priority target” for the initial portion of the Intercept Phase. It is possible that one member of a hostile formation may meet Commit criteria, while the nearest target in the same formation does not. In that case, the nearest target thought to be hostile (regardless of ID) in the formation should be the priority target. Prior to the first weapons launch the priority target should be made the PDT.

When multiple targets satisfy Commit Criteria, a prioritization scheme is required. Priority will be assigned in the following order of precedence during the initial portion of the Intercept Phase:

- 1) Nearest hostile fighter inside threat weapons range with a TAA greater than 120 deg;
- 2) Nearest Hostile bomber.

Note that priorities may change during the Intercept Phase. The pilot will need to monitor the tactical situation closely to determine the current priority. Whenever the priority target changes, the pilot should adjust the PDT to the new priority target as quickly as possible.

Course control:

While in the forward hemisphere of the priority target, and prior to launching all MRMs, maintain a “Collision Course” relative to the primary target (Collision Steering/Aim Dot centered). If Collision Course would preclude radar coverage of all HOSTILE targets, maintain as close to Collision Course as possible while retaining radar coverage of all HOSTILE or UNKNOWN targets. Remain within the designated threat sector or friendly airspace at all times.

After committing all MRMs, if still in the forward hemisphere of all HOSTILE bombers, turn away from the bombers in the closest direction toward Homeplate (or away from the nearest hostile fighter if any are detected) as far as possible while maintaining radar coverage until the last MRM launched has reached Active range. Maintain radar PDT on last MRM target unless a defensive reaction is required (defined below). When the last MRM becomes Active immediately turn in the closest direction directly toward Homeplate.

Appendix A. (continued).

Maintain course directly toward Homeplate until the last target attacked by MRM has been dropped from the radar track file (i.e., PDT is broken) Then immediately turn in the closest direction toward the estimated position of the nearest bomber.

If reaching the rear hemisphere of all bombers before launching all MRMs, turn in the closest direction (or away from the nearest HOSTILE fighter if any are detected) to establish a Collision Course relative to the nearest bomber. As bombers are attacked, transition to Collision Course versus the nearest remaining bomber against which a missile is not currently targeted.

If any bombers remain after expending all missiles, maintain Collision Course on the nearest remaining bomber until reaching 6,000 ft range, then commence a gun attack.

Airspeed control:

Conventional Cockpit - Maintain a 50-kt true airspeed (TAS) advantage over the priority target.

Candidate Cockpit - Maintain a .1-Mach airspeed advantage over the priority target.

Both Cockpits - Make positive corrections toward the desired airspeed using the throttle.

Altitude control:

Follow vertical Collision-Course guidance during the Intercept/Attack Phase except while awaiting MRM timeout. During timeout periods against bombers, maintain level flight at present altitude. Make altitude corrections at any desired rate while maintaining target airspeed.

Radar mode control:

Remain in Track-While-Scan (TWS) mode until within 10 NM of hostile targets, then employ Close-In Combat (CIC) modes to obtain STT if desired.

Radar range select:

When possible, select the radar range scale that places the priority target in the upper half of the radar display.

Radar azimuth limit control:

Select the minimum azimuth limit that provides radar coverage of all the hostile targets, assuming all six (6) hostile targets have been identified. If all hostile targets have NOT been identified select +/- 60-deg azimuth limit.

Radar azimuth center control:

Whenever less than +/- 60-deg azimuth limit is selected, adjust radar search azimuth center to provide coverage of all hostile targets.

Radar elevation bar control:

When all hostile targets have been identified, select the minimum elevation bars that provide coverage of all these targets. When coverage of all hostile targets is not possible even with the maximum bars, select 8 bars. When all hostile targets have NOT been identified, select the minimum

Appendix A. (continued).

bars necessary to provide coverage from the surface (2,000 MSL) to at least 50,000 MSL (or 8 bars if the specified altitude coverage is not possible) at the range of the priority target.

Radar elevation (Thumbwheel) control:

After all hostile targets have been identified, adjust radar elevation to provide coverage of all hostile targets. When radar coverage cannot be provided for all hostile targets, adjust elevation to cover the maximum number of hostile targets while continuing to cover the priority target. When all hostile targets have NOT been identified, adjust radar elevation so as to provide coverage of the surface (2,000 MSL) at the range of the priority target.

Primary designated target (PDT) control:

Maintain a PDT on the priority target while in the Intercept/Attack Phase.

- Note: Do not establish a Single-Target Track (STT) while in the Intercept Phase except by use of radar CIC modes.

Weapons selection:

Select the longest range weapon available while in the Intercept/Attack Phase

1.3 Weapons Employment

Weapons may be employed at any time following the Commit call. When multiple targets are within range, engage the priority target (as defined above) first. The next weapon will be committed, in order as rapidly as possible, against the next closest HOSTILE bomber.

- Note: weapons employment against HOSTILE fighters will be treated below under Defensive Reactions.

The longest-range weapons available will be expended first. Only one weapon will be fired at a given target as long as that weapon has a possibility of achieving a kill. Weapons will be fired as soon as possible after the target enters the maximum indicated range of the weapon.

Course control:

Follow weapons system guidance (i.e., center the Collision Course/Aim Dot), when available, as quickly as practical, and maintain Collision Course until reaching MRM launch range.

When in the forward hemisphere of the priority target with all MRMs expended and SRMs and/or gun ammo remaining, perform a "Stern Conversion" as follows:

- Maintain Collision Course if outside 25 NM,
- If inside 25 NM with TAA less than 135 deg, turn to lead target as far as possible while maintaining radar contact.
 - Maintain this course until TAA increases to 135 deg, reaching a point within 1 NM of maximum SRM launch range (with SRMs available), or 1 NM, whichever occurs first.
 - If TAA remains less than 135 deg, conduct a SRM/gun attack, as prescribed below.
 - If TAA increases to 135 deg prior to reaching 10 NM range, turn to Collision Course until reaching 10 NM, then follow pure pursuit (i.e., hold target on nose) until reaching weapons parameters.

Appendix A. (continued).

- If inside 25 NM with TAA greater than 135 deg, turn away from target as far as possible, toward the side with greatest lateral separation, while maintaining radar contact.
 - Maintain this course until TAA decreases to 135 deg or reaching 5 NM range.
 - If TAA remains greater than 135 deg at 5 NM, ensure the target is as far off the nose as possible (maintaining radar contact), then follow pure pursuit until reaching weapons parameters.
 - If TAA decreases to 135 deg before reaching 10 NM range, turn to Collision Course until reaching 10 NM, then follow pure pursuit until reaching weapons parameters.
 - If TAA decreases to 135 deg inside 10 NM range, continue current course until 5 NM, then follow pure pursuit until reaching weapons parameters.

When in the rear hemisphere of the priority target, maintain Collision Course until reaching MRM launch range (MRMs available), within 1 NM of SRM range (MRMs not available, SRMs available), or 1 NM (guns only available).

Remain within the designated threat sector or friendly airspace at all times.

Airspeed control:

Conventional Cockpit - Maintain a 50-kt TAS advantage over the priority target while in the target's forward hemisphere. When in the target's rear hemisphere, maintain maximum overtake (including afterburner) until approaching weapons launch parameters.

Candidate Cockpit - Maintain a .1-Mach airspeed advantage over the priority target while in the target's forward hemisphere. When in the target's rear hemisphere, maintain maximum overtake (including afterburner) until approaching weapons launch parameters.

Both Cockpits - Make positive corrections toward the desired airspeed using throttle (and speedbrakes if desired).

Altitude control:

Follow weapons system climb/descent guidance.

Radar mode control:

Remain in Track-While-Scan (TWS) mode until within 10 NM of hostile targets, then employ CIC modes for STTs if desired. Ensure STT is selected prior to a gun attack.

Radar range select:

When possible, select the radar range scale that places the priority target in the upper half of the radar display.

Radar azimuth limit control:

When all hostile targets (6) are identified, select the minimum azimuth limit that provides radar coverage of all hostile targets. Otherwise, select +/- 60-deg radar azimuth limit.

Appendix A. (continued).

Radar azimuth center control:

Whenever less than +/- 60-deg azimuth limit is selected, adjust radar search azimuth center to provide coverage of all hostile targets.

Radar elevation bar control:

When all hostile targets are identified select the minimum elevation bars that provide coverage of all hostile targets. Otherwise, select 8 bars.

Radar elevation (Thumbwheel) control:

Adjust radar elevation to provide coverage of all identified hostile targets. When radar coverage cannot be provided to all identified hostile targets, adjust elevation to cover the maximum number of hostile targets currently engaged by MRMs outside active range.

Primary designated target (PDT) control:

Maintain a PDT on the next target to be engaged with missiles when outside 10 NM range. Once all targets meeting commit criteria have been engaged, maintain a PDT on the last target engaged.

- Note: Do not establish a STT except by use of radar CIC modes.

Weapons selection:

Select the longest range weapon available.

SRM Uncage Select:

Uncage the SRM seeker and ensure target track by SRM before launch.

1.4 Defensive Reactions

Since the primary mission of the subject pilot in this evaluation is defense against bomber attacks, threat fighter escorts are to be avoided if possible. Any attack or defense against threat fighters or weapons will be defined as a "Defensive Reaction." Defensive Reactions are allowed ONLY under the following condition.

- 1) Detection of a HOSTILE radar missile targeted at the friendly fighter;
- 2) Warning of a HOSTILE fighter radar track within a lethal weapons envelope;
- 3) Detection of a HOSTILE fighter within lethal weapons range with a TAA of 120 deg or greater;
- 4) Detection of a HOSTILE fighter within 10 NM.

When the pilot detects either of the conditions listed above, he should call "Defensive." Following completion of a defensive reaction, when neither of the above conditions exist, the pilot should call "Offensive" and resume the appropriate phase. Normally this would be the Intercept/Attack or Egress Phase, whichever applies at the time. Note that there may be multiple Defensive Reactions during the mission.

When multiple threats satisfy Defensive Reaction criteria, the priority of threats will be in the order listed above, with the closest threat in the higher priority condition receiving priority. Defensive reactions described below should be performed relative to the current priority threat, which may change during with time.

Course control:

(Condition 1) -

- Perform a sustained-G (see airspeed guidance below) descending (see altitude guidance below) turn away from the missile to place it at 6 o'clock and hold it there until the missile is judged to be within 15 secs of intercept;
- When the missile is judged to be within 15 secs of intercept, perform a sustained-G (see airspeed guidance below) descending (see altitude guidance below) turn toward the missile to place it at a 1:30 or 10:30 position and hold it there until the missile is judged to be within 5 secs of intercept;
- When the missile is judged to be within 5 secs of intercept perform a maximum-G nose-low break turn toward the missile. Continue this break turn until the missile passes its point of closest approach, even if the turn causes the missile to cross the nose.
- Dispense 2 chaff bundles (one dispense action) each time the threatening missile passes through the defending aircraft's beam. For long-range Defensive Reactions this will normally occur in the initial turn away, and again during the turn back toward the missile. In addition, dispense chaff at least once during the "last-ditch" break turn at end-game.
- Threat missiles are the primary threat. If during the prescribed defensive maneuver an opportunity is presented to attack the threatening HOSTILE fighter, employ weapons as available as long as missile defense is not compromised.

(Condition 2) -

- If a HOSTILE missile has been detected, proceed as in Condition 1 above.
- If MRMs are available, attempt to acquire the offending HOSTILE fighter on radar, launch a MRM as quickly as possible, and perform an immediate "A-pole" maneuver (described below). If only SRMs and/or guns are available, perform a "Radar Missile Defense" maneuver:

Immediately turn nose-low in the nearest direction to place the threat in the left or right beam area. (If turning in the nearest direction to the beam also brings the fighter nearer to another threat fighter, turn away from the second threat.)

Reverse the direction of turn (forward-hemisphere threat) or relax the turn (rear-hemisphere threat), turning just fast enough to hold the threat as near as possible to the beam. Continue to "arc" around the threat, dispensing chaff approximately every 10 secs, until the threat radar lock is broken, a threat missile is detected, the threat is estimated to have reached 5 NM range, or 60 deg of heading change has been completed during the arc maneuver.

If, during the Radar Missile Defense maneuver, the threat radar lock is broken, immediately turn back toward the threat and attempt to acquire a radar contact. Then proceed as in Condition 3 or 4 below, as appropriate.

If, during the Radar Missile Defense maneuver, a HOSTILE missile is detected, perform as described in Condition 1 above.

If, during the Radar Missile Defense maneuver, the threat is estimated to have reached 5 NM range or 60 deg of heading change has been completed in the arc maneuver, select Sleuable Scan Lock radar mode in the direction of the threat. Then turn hard toward the threat direction while attempting to acquire a radar lock.

Once the threat is detected visually, maneuver as quickly as possible to SRM or gun firing parameters, in that order of preference.

Appendix A. (continued).

- If a threat is detected in the rear hemisphere within SRM range, perform a max-G, nose-low break turn toward the threat, deselect afterburner if engaged, and dispense both chaff and flares at least twice during the break. Attempt to acquire the target visually (with the help of radar if necessary) and maneuver to weapons-firing parameters (order of preference MRM, SRM, guns) as quickly as possible.

Remain within the designated threat sector or friendly airspace at all times.

(Condition 3) -

- If a HOSTILE missile has been detected, proceed as in Condition 1 above.
- If MRMs are available, maneuver to attain MRM firing parameters and launch a single MRM as quickly as possible. Then immediately perform an A-pole maneuver:

Perform a nose-low (see Altitude guidance below) sustained turn (see Airspeed guidance below) AWAY from the target. (If turning away from the target will bring the fighter nearer to another threat fighter, turn in the other direction.)

As the target approaches the limits of radar azimuth coverage in the turn, check that the MRM in flight is Active. If not, stop the turn until the MRM is active, then continue the turn to place the target as near as possible to the 6-o'clock position.

- Continue to dive away at maximum speed until the radar track file of the target is lost. Then perform a level sustained turn back toward the estimated target position in either direction (but away from other threat fighters if present).
- Radar search, monitoring RWR, etc. As soon as the target is confirmed destroyed, return to the appropriate phase of the mission. If the target survived and still meets Defensive Reaction criteria, repeat the MRM launch/A-pole sequence, or other Defensive Reaction as appropriate.

If only SRMs and/or guns are available, perform a level sustained turn away from the threat to the limits of radar azimuth coverage. (If turning away from the target will bring the fighter nearer to another threat fighter, turn in the other direction.) Maneuver to hold the threat near radar azimuth limits and attempt to arc around the threat until TAA decreases to below 120 deg. If TAA is reduced to below 120 deg before a HOSTILE missile is detected or a threat radar lock is indicated, return to the appropriate phase. Otherwise:

If a threat missile is detected, perform as prescribed in Condition 1 above.

If a threat radar lock is detected, perform as prescribed in Condition 2 above.

(Condition 4):

- If MRMs are available, maneuver to attain launch parameters and launch a single MRM as quickly as possible. Following MRM launch, turn away from the target to the limits of radar azimuth coverage. (If turning away from the target brings the fighter nearer to another threat fighter, turn the other way.) Monitor the target to confirm its destruction. As soon as destruction is confirmed, resume the appropriate phase. If the target survives, repeat the process until the target is destroyed or MRMs are expended.
- If only SRMs and/or guns are available, disengage from the threat if practical and resume appropriate phase. If disengagement cannot be completed successfully, maneuver to attain firing parameters for a SRM or guns, in that order of preference, and destroy the threat as quickly as possible. Then resume the appropriate phase.

Appendix A. (continued).

Airspeed control:

Maintain maximum power during the Defensive Reaction Phase unless otherwise indicated (as in SRM defense).

Conventional Cockpit - During sustained turns indicated above, maximum G should be employed when airspeed is greater than 412 KIAS. G should then be reduced as necessary to maintain 412 KIAS, or to 2Gs, whichever is greater.

Candidate Cockpit - During sustained turns indicated above, maximum G should be employed when airspeed is greater than corner speed. G should then be reduced as necessary to maintain corner speed, or to 2Gs, whichever is greater.

Altitude control:

(Condition 1) -

- When performing defensive reactions to hostile missiles and above 5,000 MSL altitude, maintain a nose-low attitude of at least 10 deg until passing 6,000 MSL, at which time the descent may be reduced in order to avoid ground collision. Continue to descend to below 5,000 MSL, then level off.
- When below 5,000 MSL, maintain currently assigned altitude;
- During a last-ditch defensive missile break, maintain at least a 10-deg nose-low attitude unless a level-off is necessary to avoid hitting the ground.

(Condition 2) -

- Follow weapons-system guidance (Aim Dot) when maneuvering to launch weapons.
- During Radar Missile Defense maneuvers or SRM defensive break turns, maintain at least 10-deg nose low while above 6,000 MSL, then reduce dive angle as necessary to level off below 5,000 MSL.
- Avoid hitting the ground.

(Condition 3):

- Follow weapons-system guidance (Aim Dot) when maneuvering to launch weapons.
- During A-pole maneuvers maintain at least 10-deg nose low while above 6,000 MSL, then reduce dive angle as necessary to level off below 5,000 MSL.

(Condition 4):

- Follow weapons-system guidance (Aim Dot) when maneuvering to launch weapons.

Radar mode control:

When not prescribed above, select the radar mode that allows quickest acquisition of the threat while performing Defensive Reactions. This normally indicates one of the CIC modes whenever the threat is detected visually prior to radar detection.

Appendix A. (continued).

Radar range select:

When possible, select the radar range scale that places the closest threat fighter in the upper half of the radar display.

Radar azimuth limit control:

When performing an A-pole, Radar Missile Defense maneuver, or attempting to avoid a threat in Condition 4 without MRMs, ensure that the radar azimuth limit on the threat side is 60 deg. Note that, depending on the radar azimuth center selected, this goal may be accomplished with any azimuth limit selected.

Radar azimuth center control:

Adjust radar search azimuth to provide coverage of all threat fighters meeting Defensive Reaction criteria, if possible.

Radar elevation bar control:

Select elevation bars as desired.

Radar elevation (Thumbwheel) control:

Adjust radar elevation to provide coverage of all threat fighters meeting Defensive Reaction criteria when possible.

Primary designated target (PDT) control:

Maintain a PDT on the highest priority threat fighter whenever that threat is within radar coverage limits.

Weapons selection:

Select the longest range weapon available while performing Defensive Reactions.

Weapons launch:

(Conditions 2, 3, and 4) -

- When called for above, fire the longest-range weapon available at the highest priority threat fighter as quickly as possible after meeting launch parameters. Fire only one weapon per target until assessing results of launch. If first weapon is determined to be ineffective and further attacks are prescribed above, fire another weapon as soon as possible. If multiple threat fighters meet defensive reaction criteria, launch at each in order of range, closest first.

1.5 Weapons Employment

MRM launches should only be performed with a radar-designated target (either PDT or STT). That is, no MRMs should be fired in the boresight, no-lock mode. MRMs should be launched with the Aim Dot (on HUD, HDD, HMD, or radar) as close to the center as possible, and never with the Aim Dot outside the Allowable Steering Error (ASE) circle. No MRMs should be launched outside displayed launch range envelope boundaries (i.e., no "firing for effect"). All MRMs should be expended before other weapons are employed.

SRM launches should only be performed with a radar-designated target (either PDT or STT). SRMs should be launched only with the seeker uncaged and tracking the intended target with a good IR-track audio tone. The intended target (and SRM seeker diamond) for an SRM launch should be within the HUD field of view at launch, with the Aim Dot as close to centered in the ASE circle as possible. No SRMs should be launched outside displayed launch envelope boundaries. SRMs should not be fired while MRMs are available.

Gun attacks should only be performed when a radar STT is available on the intended target. The maximum range for a gun attack is 2,000 ft. The gun should be fired only in short (1-sec) bursts. Gun attacks should not be performed while missiles are available.

1.6 Egress Phase

The Egress Phase begins when:

- All hostile bombers have been destroyed, or;
- "JOKER" fuel state is reached (2,500 lbs);
- All weapons are expended.

Note: the Egress Phase may be preempted by a Defensive Reaction.

When any of the conditions for the Egress Phase have been met, the pilot should announce "Egress." The Egress Phase ends when the fighter reaches friendly airspace. At this point, the pilot should announce "Safe, Knock it off."

Course control:

Maintain a direct course toward "Homeplate."

Airspeed control:

Maintain maximum afterburner (MAX) until reaching JOKER fuel state, then reduce throttle to MIL power.

Altitude control:

Maintain level flight.

Radar mode control:

Select Track-While-Scan (TWS) mode while in the Egress Phase.

Appendix A. (continued).

Radar range select:

When possible, select the radar range scale that places the Homeplate in the upper half of the radar display.

Radar azimuth limit control:

Select +/- 60-deg azimuth limit while in the Egress Phase.

Radar azimuth center control:

Not required when +/- 60-deg azimuth limits selected.

Radar elevation bar control:

Select the minimum bars necessary to provide coverage from the surface (2,000 MSL) to at least 50,000 MSL at Homeplate.

Radar elevation (Thumbwheel) control:

Adjust radar elevation so as to provide coverage of all known HOSTILE targets within the azimuth limits of the radar while simultaneously, if possible, providing coverage of the surface (2,000 MSL) at the range of Homeplate.

Primary designated target (PDT) control:

Maintain a PDT on the nearest HOSTILE target detected while in the Egress Phase.

Note: Do not establish a radar STT while in the Egress Phase.

Weapons selection:

Select the longest range weapon available while in the Egress Phase.

Appendix B. On-Line Pilot-Aircraft System Output Measures.

Listing of On-Line Pilot-Aircraft System Output Measures

- 1) 6 DOF Position/ Attitude data for each aircraft
- 2) Time and Target of each radar single-target track
- 3) Time and Target of each change in radar contact/Lock Status
- 4) Time and Target of each commit decision
- 5) Calibrated airspeed
- 6) Angle of attack
- 7) Radar range selected
- 8) Radar elevation bars selected
- 9) Radar antenna elevation center selected
- 10) Radar azimuth selected
- 11) Radar mode selected
- 12) HMD position and orientation
- 13) Weapons mode selected
- 14) Weapons load
- 15) Chaff/flare load
- 16) Chaff/flare dispense command
- 17) Time of each GCAS alert
- 18) Number of GCAS alerts per trial
- 19) Time of aircraft for all ground impacts
- 20) Time of each visual detection from audio tapes
- 21) Fuel state
- 22) Time of commencing egress
- 23) Time of "knock it off"
- 24) Level of IR missile tone
- 25) Roll rate (labeled left/right)
- 26) Deviation from prescribed CAP pattern
- 27) Outcome of each trial (Won, Lost)
- 28) Number of Bomber kills
- 29) Number of Threat Station Kills
- 30) Number of SRM Launched
- 31) Number of MRM Launched
- 32) Number of SRM hits
- 33) Number of MRM hits
- 34) Number of rounds of gunfire
- 35) Number of Friendly F-15 Kills
- 36) Number of Ground Impacts
- 37) Kill ratio

SWAT RATINGS

SUBJECT ID: _____ **TASK ID:** _____

DATE: _____ **SESSION** _____

TIME LOAD

1) LOWEST _____ 2) MODERATE _____ 3) HIGHEST _____

MENTAL EFFORT LOAD

1) LOWEST _____ 2) MODERATE _____ 3) HIGHEST _____

PSYCHOLOGICAL STRESS LOAD

1) LOWEST _____ 2) MODERATE _____ 3) HIGHEST _____

TIME LOAD

1) OFTEN HAVE SPARE TIME. INTERRUPTIONS OR OVERLAP AMONG ACTIVITIES OCCUR INFREQUENTLY OR NOT AT ALL

2) OCCASIONALLY HAVE SPARE TIME. INTERRUPTIONS OR OVERLAP AMONG ACTIVITIES OCCUR FREQUENTLY.

3) ALMOST NEVER HAVE SPARE TIME. INTERRUPTIONS OR OVERLAP AMONG ACTIVITIES ARE VERY FREQUENT OR OCCUR ALL THE TIME.

MENTAL EFFORT LOAD

1) VERY LITTLE CONSCIOUS MENTAL EFFORT OR CONCENTRATION REQUIRED. ACTIVITY IS ALMOST AUTOMATIC, REQUIRING LITTLE OR NO ATTENTION

2) MODERATE CONSCIOUS MENTAL EFFORT OR CONCENTRATION REQUIRED. COMPLEXITY OF ACTIVITY IS MODERATELY HIGH DUE TO UNCERTAINTY, UNPREDICTABILITY, OR UNFAMILIARITY, CONSIDERABLE ATTENTION IS REQUIRED.

3) EXTENSIVE MENTAL EFFORT AND CONCENTRATION ARE NECESSARY, VERY COMPLEX ACTIVITY REQUIRING TOTAL ATTENTION.

PSYCHOLOGICAL STRESS LOAD

1) LITTLE CONFUSION, RISK, FRUSTRATION, OR ANXIETY AND CAN EASILY BE ACCOMMODATED.

2) MODERATE STRESS DUE TO CONFUSION, FRUSTRATION, OR ANXIETY NOTICEABLY ADDS TO WORKLOAD. SIGNIFICANT COMPENSATION IS REQUIRED TO MAINTAIN ADEQUATE PERFORMANCE.

3) HIGH TO VERY INTENSE STRESS DUE TO CONFUSION, FRUSTRATION, OR ANXIETY, HIGH TO EXTREME DETERMINATION AND SELF-CONTROL REQUIRED.

Appendix D. Subjective Workload Dominance Technique (SWORD) Rating Scale

Pilot ID: _____ Date: _____

FITE Lab SWORD Evaluation

- The purpose of this evaluation is to quantify your opinion regarding the mental workload you experienced while using the two cockpits.
- The workload will be evaluated by cockpit for three different segments of the mission.
- The cockpit/phase combinations you will be evaluating are:
 - Conventional (Old) Cockpit/CAP Phase Old/CAP
 - Conventional (Old) Cockpit/Intercept Phase Old/Inter
 - Conventional (Old) Cockpit/Weapons Phase Old/Weap
 - Conventional (Old) Cockpit/Egress Phase Old/Egress
 - Candidate (New) Cockpit/CAP Phase New/CAP
 - Candidate (New) Cockpit/Intercept Phase New/Inter
 - Candidate (New) Cockpit/Weapons Phase New/Weap
 - Candidate (New) Cockpit/Egress Phase New/Egress
- To fill out the survey you will be making a series of relative comparisons. The procedure is explained on the next page.

Appendix D. Continued

Filling Out the Survey Forms

- The survey consists of a series of relative judgments comparing two sets of equipment. For example, equipment configuration "A" might be compared to "B."
- If performing the mission with A would probably (in your opinion) require exactly the same level of mental workload as doing it with B, then you mark the form in the center.

>>>> >>> >> > EQUAL < << <<< <<<<

A	_____	X	_____	B
---	-------	---	-------	---

- If A were going to cause a little more workload, then you would move your mark a little closer to A.

>>>> >>> >> > EQUAL < << <<< <<<<

A	_____	X	_____	B
---	-------	---	-------	---

- If A were going to cause a lot more workload you would move your mark very close to A.

>>>> >>> >> > EQUAL < << <<< <<<<

A	X_____		_____	B
---	--------	--	-------	---

- On the other hand if B were going to cause moderately more workload then you would move your mark in that direction.

>>>> >>> >> > EQUAL < << <<< <<<<

A	_____		X_____	B
---	-------	--	--------	---

MENTAL WORKLOAD Evaluation

>>>> >>> >> > EQUAL < << <<< <<<<													
Old/CAP	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	Old/Inter
Old/CAP	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	Old/Weap
Old/CAP	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	Old/Egress
Old/CAP	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	New/CAP
Old/CAP	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	New/Inter
Old/CAP	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	New/Weap
Old/CAP	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	New/Egress
Old/Inter	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	Old/Weap
Old/Inter	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	Old/Egress
Old/Inter	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	New/CAP
Old/Inter	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	New/Inter
Old/Inter	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	New/Weap
Old/Inter	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	New/Egress
Old/Weap	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	Old/Egress
Old/Weap	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	New/CAP
Old/Weap	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	New/Inter
Old/Weap	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	New/Weap
Old/Weap	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	New/Egress

MENTAL WORKLOAD Evaluation

>>>>	>>>	>>	>	EQUAL	<	<<	<<<	<<<<
Old/Egress	_____	_____	_____	_____	_____	_____	_____	New/CAP
Old/Egress	_____	_____	_____	_____	_____	_____	_____	New/Inter
Old/Egress	_____	_____	_____	_____	_____	_____	_____	New/Weap
Old/Egress	_____	_____	_____	_____	_____	_____	_____	New/Egress
<hr/>								
New/CAP	_____	_____	_____	_____	_____	_____	_____	New/Inter
New/CAP	_____	_____	_____	_____	_____	_____	_____	New/Weap
New/CAP	_____	_____	_____	_____	_____	_____	_____	New/Egress
<hr/>								
New/Inter	_____	_____	_____	_____	_____	_____	_____	New/Weap
New/Inter	_____	_____	_____	_____	_____	_____	_____	New/Egress
<hr/>								
New/Weap	_____	_____	_____	_____	_____	_____	_____	New/Egress

Appendix D. Continued

Pilot ID: _____

FITE Lab SWORD Evaluation -- Scoring Form

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	SWORD Ratings
(1) Old/CAP	1								_____
(2) Old/Inter		1							_____
(3) Old/Weap			1						_____
(4) Old/Egress				1					_____
(5) New/CAP					1				_____
(6) New/Inter						1			_____
(7) New/Weap							1		_____
(8) New/Egress								1	_____

Consistency Test: $S^2 =$ _____ P / F

Appendix E. Situation Awareness Rating Technique

SUBJECT: _____ TASK ID: _____

DATE: _____ SESSION: _____

SART

DIMENSIONS	RATING SCALE						
	Low						High
	1	2	3	4	5	6	7
DEMAND							
SUPPLY							
UNDERSTANDING							

	Low						High
	1	2	3	4	5	6	7
SITUATION AWARENESS							

DEMANDS ON ATTENTIONAL RESOURCES

Demands placed on your attentional resources by flying, navigation, and shooting tasks. How much the task's instability, variability, and complexity affected your SA.

SUPPLY OF ATTENTIONAL RESOURCES

Think of your mental state while doing the task. Rating should reflect your degree of arousal, your spare mental capacity, your ability to concentrate, and your ability to divide attention across multiple tasks.

UNDERSTANDING OF THE SITUATION

How your understanding and knowledge of the situation affects the task performance and SA. Please rate the quantity of information available to you, the quality of that information, and your familiarity with the task.

OVERALL SA

You should assume a broad perspective that takes into account your entire experience in the task, and to generate a single rating that you feel best represents your SA while performing the task.

Appendix F. Cognitive Compatibility Situation Awareness Rating Technique

SUBJECT: _____ TASK ID: _____

DATE: _____ SESSION: _____

CC-SART

DIMENSIONS	RATING SCALE						
	Low						High
	1	2	3	4	5	6	7
LEVEL OF PROCESSING							
EASE OF REASONING							
ACTIVATION OF KNOWLEDGE							

LEVEL OF PROCESSING: Degree to which the situation involves, at the low level natural automatic, intuitive and associated processing or, at the high level analytic, considered, conceptual and abstract processing.

EASE OF REASONING: Degree to which the situation, at the low level, is confusing and contradictory or, at the high level, is straightforward and understandable.

ACTIVATION OF KNOWLEDGE: Degree to which the situation, at the low level, is strange and unusual or, at the high level, is recognizable and familiar.

PILOT INTERFACE EVALUATION

COCKPIT BY PHASE

DESCRIPTION OF 13-D CC-SART DIMENSIONS	RATING						
	Low						High
	1	2	3	4	5	6	7
<u>1. LEVEL OF PROCESSING</u> Degree to which the situation involves, at the low level natural, automatic, intuitive and associated processing or, at the high level analytic, considered, conceptual and abstract processing.							
<u>1.1 NATURALNESS</u> Degree to which the situation appears normal, as in nature, and not requiring learning, or is obvious.							
<u>1.2 AUTOMATICITY</u> Degree of habit and lack of conscious thought, or of instinctiveness in the situation							
<u>1.3 ASSOCIATION</u> Degree of mental connection of ideas, or of feelings, or of sensations, or of expectations in the situation.							
<u>1.4 INTUITIVENESS</u> Level of spontaneity and insightfulness involved in the situation.							
<u>2. EASE OF REASONING</u> Degree to which the situation, at the low level, is confusing and contradictory or, at the high level, is straightforward and understandable.							
<u>2.1 STRAIGHTFORWARD</u> Degree to which the situation is direct, or clear cut, or has clarity.							
<u>2.2 CONFUSABILITY</u> Degree to which the situation is perplexing and bewildering, or has complexity.							
<u>2.3 UNDERSTANDABILITY</u> Degree to which the meaning of the situation is known and comprehensible, or has logicalness and consistency.							
<u>2.4 CONTRADICTION</u> Degree of antagonism, or of negation, or of confliction the situation.							
<u>3. ACTIVATION OF KNOWLEDGE</u> Degree to which the situation, at the low level, is strange and unusual or, at the high level, is recognisable and familiar.							
<u>3.1 RECOGNISABILITY</u> Degree to which the situation belongs to the same class as something previously seen or known.							
<u>3.2 FAMILIARITY</u> Degree of acquaintance and past experience with the situation.							

Appendix H. Debrief Questionnaire.

DEBRIEF QUESTIONNAIRE

1. On a scale from 1 - 10, with 10 being "extremely difficult," how hard did you find the task of maintaining the prescribed CAP pattern?
2. Difficulty in maintaining prescribed CAP airspeed?
3. Difficulty of maintaining prescribed CAP altitude?
4. On a scale of 1 - 100, what percentage of your available attention do you estimate was allocated to the task of maintaining the prescribed track in the CAP pattern?
5. Percentage of attention allocated to maintaining prescribed CAP airspeed?
6. Percentage of attention allocated to maintaining prescribed CAP altitude?
7. What do you estimate was your greatest deviation from the prescribed CAP pattern? +/- _____ NM
8. What do you estimate was your greatest deviation from the prescribed CAP airspeed? +/- _____ KCAS
9. What do you estimate was your greatest deviation from the prescribed CAP altitude? +/- _____ FT

Appendix H. (continued).

10. What additional information did you require, or would have been helpful, for maintaining prescribed CAP pattern track, airspeed, or altitude?
11. Do you have any comments on the desirability of the navigation, airspeed, or altitude displays for accomplishing the task of maintaining a prescribed CAP pattern?
12. On a scale from 1 - 10, with 10 being "extremely difficult," how hard did you find the task of determining whether targets satisfied prescribed commit criteria?
13. How long, on average, do you estimate it took to determine a target had met commit criteria, once that criteria had actually been met? _____ SEC
14. Did you make any inaccurate commit decisions? Y/N
If yes, how many? _____
15. What additional information did you require, or would have been helpful, for making the commit decision?
16. Do you have any comments on the desirability of the information and displays provided for making the commit decision?
17. On a scale of 1 - 100, what percentage of your available attention do you estimate was allocated to the task of monitoring and controlling the radar while searching for targets in the CAP pattern?

Appendix H. (continued).

18. On a scale of 1 - 100, what percentage of your available attention do you estimate was allocated to the task of visually searching for targets in the CAP pattern?
19. On a scale from 1 - 10, with 10 being "extremely difficult," how hard did you find the task of determining and controlling radar search volume while in the CAP pattern?
20. What additional information did you require, or would have been helpful, for determining and controlling search volume in the CAP pattern?
21. Do you have any comments on the desirability of the information, displays, or controls provided for determining and controlling radar search volume in the CAP pattern?
22. On a scale from 1 - 10, with 10 being "extremely difficult," how hard did you find the task of performing a radar intercept to a desired point?
23. On a scale from 1 - 10, with 10 being "extremely difficult," how hard did you find the task of determining your position relative to a target during an intercept?
24. On a scale from 1 - 10, with 10 being "extremely difficult," how hard did you find the task of determining your threat from a target's weapon system during an intercept?
25. On a scale from 1 - 10, with 10 being "extremely difficult," how hard did you find the task of determining the capability of your weapon system during an intercept?

Appendix H. (continued).

26. On a scale from 1 - 10, with 10 being "extremely difficult," how hard did you find the task of determining your relative tactical advantage versus the target during an intercept?
27. On a scale from 1 - 10, with 10 being "extremely difficult," how hard did you find the task of determining your relative tactical advantage versus threats other than the primary target during an intercept?
28. What additional information did you require, or would have been helpful, for performing radar intercepts?
29. Do you have any comments on the desirability of the information, displays, or controls provided for performing radar intercepts?
30. On a scale from 1 - 10, with 10 being "extremely difficult," how hard did you find the task of identifying friendly/hostile targets?
31. What additional information did you require, or would have been helpful, for identifying friendly/hostile targets?
32. Do you have any comments on the desirability of the information, displays, or controls provided for identifying friendly/hostile targets?
33. Did you ever attempt to intercept or engage a target in error? In other words, did you mistake a friendly for a threat, or a threat fighter for a bomber, etc.? Y/N
If so, explain.
34. On a scale from 1 - 10, with 10 being "extremely difficult," how hard did you find the task of remaining within prescribed airspace while performing radar intercepts?

Appendix H. (continued).

35. Did you ever "spill out" of prescribed airspace while performing a radar intercept?
36. On a scale from 1 - 10, with 10 being "extremely difficult," how hard did you find the task of maintaining desired airspeed and altitude while performing radar intercepts?
37. On a scale of 1 - 100, what percentage of your available attention do you estimate was allocated to the task of monitoring and controlling the radar while performing a radar intercept?
38. On a scale of 1 - 100, what percentage of your available attention do you estimate was allocated to the task of visually searching for targets while performing a radar intercept?
39. On a scale of 1 - 100, what percentage of your available attention do you estimate was allocated to the task of flying the aircraft (i.e., aircraft control, monitoring parameters, navigation, etc.) while performing a radar intercept?
40. Did you experience any instances of loss of spacial awareness while performing a radar intercept? Y/N
If so, would you categorize this event as minor, moderate, or serious? Min/Mod/Ser
- * 41. Were any GCAS alerts experienced during a radar intercept?
Y/N If so, were you aware of the critical nature of your flight condition at the time? Y/N
42. On a scale from 1 - 10, with 10 being "extremely difficult," how hard did you find the task of obtaining a radar lock on a target during close-in combat? If no close-in combat, mark NONE.

Appendix H. (continued).

43. What additional information did you require, or would have been helpful, for obtaining radar locks during close-in combat?

44. Do you have any comments on the desirability of the information, displays, or controls provided for Close-In Combat (CIC) modes of the radar?

45. Which CIC did you prefer during close-in combat?

Boresight (BST)
Vertical Scan Lock (VSL)
Sleuable Scan Lock (SSL)
Helmet Mounted Display (HMD) (when available)

Why?

46. On a scale from 1 - 10, with 10 being "extremely difficult," how hard did you find the task of performing close-in combat in this controls/displays version?

47. On a scale from 1 - 10, with 10 being "extremely difficult," how hard did you find the task of determining your position relative to your primary opponents during close-in combat?

48. On a scale from 1 - 10, with 10 being "extremely difficult," how hard did you find the task of determining your threat from an opponent's weapon system during close-in combat?

49. On a scale from 1 - 10, with 10 being "extremely difficult," how hard did you find the task of determining the capability of your weapon system during close-in combat?

50. On a scale from 1 - 10, with 10 being "extremely difficult," how hard did you find the task of determining your relative tactical advantage versus your primary opponents during close-in combat?

Appendix H. (continued).

51. On a scale from 1 - 10, with 10 being "extremely difficult," how hard did you find the task of determining your relative tactical advantage versus threats other than your primary opponent during close-in combat?
52. What additional information did you require, or would have been helpful, for performing close-in combat?
53. Do you have any comments on the desirability of the information, displays, or controls provided for performing close-in combat?
54. On a scale from 1 - 10, with 10 being "extremely difficult," how hard did you find the task of remaining within prescribed airspace while performing close-in combat?
55. Did you ever "spill out" of prescribed airspace while performing close-in combat?
56. On a scale from 1 - 10, with 10 being "extremely difficult," how hard did you find the task of maintaining desired maneuver conditions while performing close-in combat?
57. On a scale of 1 - 100, what percentage of your available attention do you estimate was allocated to the task of monitoring and controlling the radar while performing close-in combat?
58. On a scale of 1 - 100, what percentage of your available attention do you estimate was allocated to the task of visually searching for targets while performing close-in combat?

Appendix H. (continued).

59. On a scale of 1 - 100, what percentage of your available attention do you estimate was allocated to the task of flying the aircraft (i.e., aircraft control, monitoring parameters, navigation, etc.) while performing close-in combat?
60. Did you experience any instances of loss of spacial awareness while performing close-in combat? Y/N If so, would you categorize this event as minor, moderate, or serious? Min/Mod/Ser
- * 61. Were any GCAS alerts experienced during close-in combat? Y/N If so, were you aware of the critical nature of your flight condition at the time? Y/N
- * 62. What additional information did you require, or would have been helpful, for avoiding or recovering from critical low-altitude situations?
63. Do you have any comments on the desirability of the information or displays provided for avoiding or recovering from critical low-altitude situations?
64. Did you ever lose control of the aircraft during close-in combat? That is, did the aircraft ever do something you did not intend or expect, were you ever below 100 KCAS, did you ever have to recover from a stall or spin, etc.? Y/N
If so, explain.
65. On a scale from 1 - 10, with 10 being "extremely difficult," how hard did you find the task of determining permissible and optimum weapons launch parameters?
66. What additional information did you require, or would have been helpful, for determining permissible and optimum weapons launch parameters?

Appendix H. (continued).

67. Do you have any comments on the desirability of the weapons envelope displays for accomplishing the weapons employment task?
68. Did you ever UNintentionally fire a weapon outside indicated permissible launch parameters? Y/N
If so, explain.
69. Did you ever INTENTIONALLY fire a weapon outside indicated permissible launch parameters? Y/N
If so, explain.
70. On a scale from 1 - 10, with 10 being "extremely difficult," how hard did you find the task of determining the location, status, and threat of hostile aircraft?
71. What additional information did you require, or would have been helpful, for determining the location, status, and threat of hostile aircraft?
- ** 72. Do you have any comments on the desirability of the defensive systems displays (i.e., RWR and hostile weapons envelope boundaries) for determining the location, status, and threat of hostile aircraft?
73. What additional information did you require, or would have been helpful, for determining the status of defensive expendable systems?
74. Do you have any comments on the desirability of the controls and displays for the expendable system?
75. Were you shot down? Y/N
If so, were you aware of the seriousness of the threat at the time? Y/N
If not, explain.

Appendix H. (continued).

76. Were you always aware of the required response to any threat detected? Y/N
If not, explain.

77. On a scale from 1 - 10, with 10 being "extremely difficult," how hard did you find the task of determining when egress criteria had been met?

78. What additional information did you require, or would have been helpful, for determining egress criteria?

79. Do you have any comments on the desirability of the displays provided for determining egress criteria (i.e., fuel, weapons, expendable displays, etc.)

80. On a scale from 1 - 10, with 10 being "extremely difficult," how hard did you find the task of determining the most direct route to the safe area during egress?

81. On a scale from 1 - 10, with 10 being "extremely difficult," how hard did you find the task of determining the threat level during egress?

82. On a scale from 1 - 10, with 10 being "extremely difficult," how hard did you find the task of remaining within prescribed airspace while performing an egress?

83. Did you ever "spill out" of prescribed airspace during an egress?

84. On a scale of 1 - 100, what percentage of your available attention do you estimate was allocated to the task of visually searching for targets while performing an egress?

85. Did you experience any instances of loss of spacial awareness while performing an egress? Y/N If so, would you categorize this event as minor, moderate, or serious? Min/Mod/Ser

Appendix H. (continued).

- * 86. Were any GCAS alerts experienced during an egress? Y/N
If so, were you aware of the critical nature of your flight
condition at the time? Y/N

87. On a scale of 1 - 100, what percentage of your available
attention do you estimate was allocated to the task of
flying the aircraft (i.e., aircraft control, monitoring
parameters, navigation, etc.) while performing an egress?

88. What additional information did you require, or would have
been helpful, for maintaining performing an egress?

89. Do you have any comments on the desirability of the
navigation, airspeed, or altitude displays for performing an
egress?

90. Do you have any additional comments about anything not
covered elsewhere in this questionnaire, including the
simulations, facilities, scenarios, procedures, etc.?

- + 91. Did you ever hit the ground during a mission? Y/N
If so, during what mission phase?

CAP

Intercept

Maneuver (within 3 NM of hostile aircraft)

Egress

If so, were you aware of the critical situation prior to
impact? Y/N

- * Ask question only for Candidate system
** Modify question for Conventional system
+ Ask question only for Conventional system

Appendix I. Order of Presentation of Interface Conditions

United States Air Force

	Trial	Cockpit Interface	Threat Altitude
Subject 7	1	Candidate	Low
	2	Candidate	Medium
	3	Candidate	High
	4	Conventional	Low
	5	Conventional	Medium
	6	Conventional	High
Subject 8	7	Conventional	Low
	8	Conventional	High
	9	Conventional	Medium
	10	Candidate	Low
	11	Candidate	High
	12	Candidate	Medium
Subject 9	13	Candidate	Medium
	14	Candidate	Low
	15	Candidate	High
	16	Conventional	Medium
	17	Conventional	Low
	18	Conventional	High
Subject 10	19	Conventional	Medium
	20	Conventional	High
	21	Conventional	Low
	22	Candidate	Medium
	23	Candidate	High
	24	Candidate	Low
Subject 7	25	Conventional	High
	26	Conventional	Low
	27	Conventional	Medium
	28	Candidate	High
	29	Candidate	Low
	30	Candidate	Medium
Subject 8	31	Candidate	High
	32	Candidate	Medium
	33	Candidate	Low
	34	Conventional	High
	35	Conventional	Medium
	36	Conventional	Low

Appendix I. (continued)

Subject 9	37	Conventional	Low
	38	Conventional	Medium
	39	Conventional	High
	40	Candidate	Low
	41	Candidate	Medium
	42	Candidate	High
Subject 10	43	Candidate	Low
	44	Candidate	High
	45	Candidate	Medium
	46	Conventional	Low
	47	Conventional	High
	48	Conventional	Medium
Subject 7	49	Conventional	Medium
	50	Conventional	Low
	51	Conventional	High
	52	Candidate	Medium
	53	Candidate	Low
	54	Candidate	High
Subject 8	55	Conventional	Medium
	56	Conventional	High
	57	Conventional	Low
	58	Candidate	Medium
	59	Candidate	High
	60	Candidate	Low
Subject 9	61	Candidate	High
	62	Candidate	Low
	63	Candidate	Medium
	64	Conventional	High
	65	Conventional	Low
	66	Conventional	Medium
Subject 10	67	Candidate	High
	68	Candidate	Medium
	69	Candidate	Low
	70	Conventional	High
	71	Conventional	Medium
	72	Conventional	Low

Appendix I. (continued)

	Trial	Cockpit Interface	Threat Altitude
Subject 11	1	Candidate	High
	2	Candidate	Low
	3	Candidate	Medium
	4	Conventional	High
	5	Conventional	Low
	6	Conventional	Medium
Subject 12	7	Conventional	High
	8	Conventional	Medium
	9	Conventional	Low
	10	Candidate	High
	11	Candidate	Medium
	12	Candidate	Low
Subject 13	13	Candidate	Medium
	14	Candidate	Low
	15	Candidate	High
	16	Conventional	Medium
	17	Conventional	Low
	18	Conventional	High
Subject 14	19	Conventional	Medium
	20	Conventional	High
	21	Conventional	Low
	22	Candidate	Medium
	23	Candidate	High
	24	Candidate	Low
Subject 11	25	Conventional	Medium
	26	Conventional	Low
	27	Conventional	High
	28	Candidate	Medium
	29	Candidate	Low
	30	Candidate	High
Subject 12	31	Candidate	Medium
	32	Candidate	High
	33	Candidate	Low
	34	Conventional	Medium
	35	Conventional	High
	36	Conventional	Low

Appendix I. (continued)

Subject 13	37	Conventional	Low
	38	Conventional	Medium
	39	Conventional	High
	40	Candidate	Low
	41	Candidate	Medium
	42	Candidate	High
Subject 14	43	Candidate	Low
	44	Candidate	High
	45	Candidate	Medium
	46	Conventional	Low
	47	Conventional	High
	48	Conventional	Medium
Subject 11	49	Candidate	Low
	50	Candidate	High
	51	Candidate	Medium
	52	Conventional	Low
	53	Conventional	High
	54	Conventional	Medium
Subject 12	55	Conventional	Low
	56	Conventional	Medium
	57	Conventional	High
	58	Candidate	Low
	59	Candidate	Medium
	60	Candidate	High
Subject 13	61	Candidate	High
	62	Candidate	Low
	63	Candidate	Medium
	64	Conventional	High
	65	Conventional	Low
	66	Conventional	Medium
Session 14	67	Conventional	High
	68	Conventional	Medium
	69	Conventional	Low
	70	Candidate	High
	71	Candidate	Medium
	72	Candidate	Low

Appendix I. (continued)

French Air Force

	Trial	Cockpit Interface	Threat Altitude
Subject 81	1	Candidate	Low
	2	Candidate	Medium
	3	Candidate	High
	4	Conventional	Low
	5	Conventional	Medium
	6	Conventional	High
Subject 82	7	Conventional	low
	8	Conventional	High
	9	Conventional	Medium
	10	Candidate	Low
	11	Candidate	High
	12	Candidate	Medium
Subject 83	13	Candidate	Medium
	14	Candidate	Low
	15	Candidate	High
	16	Conventional	Medium
	17	Conventional	Low
	18	Conventional	High
Subject 81	19	Conventional	High
	20	Conventional	Low
	21	Conventional	Medium
	22	Candidate	High
	23	Candidate	Low
	24	Candidate	Medium
Subject 82	25	Candidate	High
	26	Candidate	Medium
	27	Candidate	Low
	28	Conventional	High
	29	Conventional	Medium
	30	Conventional	Low
Subject 83	31	Conventional	Low
	32	Conventional	Medium
	33	Conventional	High
	34	Candidate	Low
	35	Candidate	Medium
	36	Candidate	High
Subject 84	1	Conventional	Medium
	2	Conventional	High
	3	Conventional	Low
	4	Candidate	Medium
	5	Candidate	High
	6	Candidate	Low

Appendix I. (continued)

Subject 85	7	Conventional	High
	8	Conventional	Medium
	9	Conventional	Low
	10	Candidate	High
	11	Candidate	Medium
	12	Candidate	Low
Subject 86	13	Candidate	High
	14	Candidate	Low
	15	Candidate	Medium
	16	Conventional	High
	17	Conventional	Low
	18	Conventional	Medium
Subject 84	19	Candidate	Low
	20	Candidate	High
	21	Candidate	Medium
	22	Conventional	Low
	23	Conventional	High
	24	Conventional	Medium
Subject 85	25	Candidate	Medium
	26	Candidate	High
	27	Candidate	Low
	28	Conventional	Medium
	29	Conventional	High
	30	Conventional	Low
Subject 86	31	Conventional	Medium
	32	Conventional	Low
	33	Conventional	High
	34	Candidate	Medium
	35	Candidate	Low
	36	Candidate	High

Appendix I. (continued)**Royal Air Force**

	Trial	Cockpit Interface	Threat Altitude
Subject 91	1	Candidate	Low
	2	Candidate	Medium
	3	Candidate	High
	4	Conventional	Low
	5	Conventional	Medium
	6	Conventional	High
Subject 92	7	Conventional	Low
	8	Conventional	High
	9	Conventional	Medium
	10	Candidate	Low
	11	Candidate	High
	12	Candidate	Medium
Subject 93	13	Candidate	Medium
	14	Candidate	Low
	15	Candidate	High
	16	Conventional	Medium
	17	Conventional	Low
	18	Conventional	High
Subject 94	19	Conventional	Medium
	20	Conventional	High
	21	Conventional	Low
	22	Candidate	Medium
	23	Candidate	High
	24	Candidate	Low
Subject 91	25	Conventional	High
	26	Conventional	Low
	27	Conventional	Medium
	28	Candidate	High
	29	Candidate	Low
	30	Candidate	Medium
Subject 92	31	Candidate	High
	32	Candidate	Medium
	33	Candidate	Low
	34	Conventional	High
	35	Conventional	Medium
	36	Conventional	Low

Appendix I. (continued)

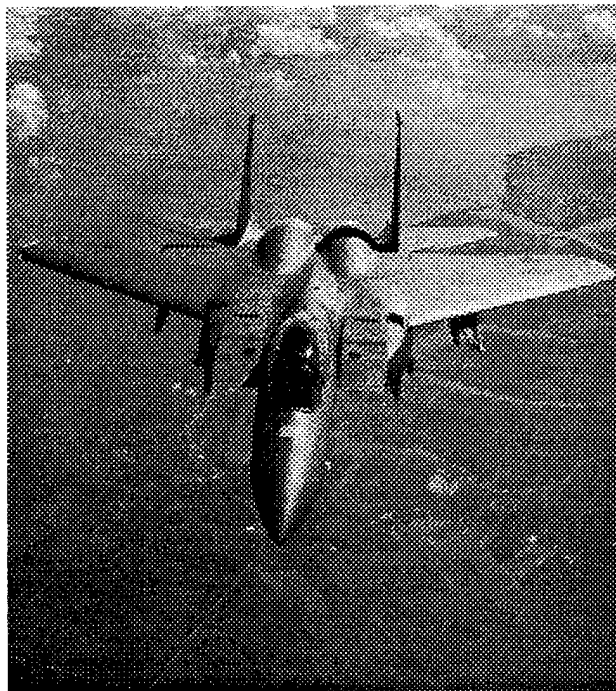
Subject 93	37	Conventional	Low
	38	Conventional	Medium
	39	Conventional	High
	40	Candidate	Low
	41	Candidate	Medium
	42	Candidate	High
Subject 94	43	Candidate	Low
	44	Candidate	High
	45	Candidate	Medium
	46	Conventional	Low
	47	Conventional	High
	48	Conventional	Medium



F.I.T.E.

Fusion Interfaces for Tactical Environments Laboratory

1995 EXPERIMENTAL COCKPIT TRAINING MANUAL



FITE LAB

EXPERIMENTAL COCKPIT TRAINING MANUAL

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List of Acronyms

A

AAA	Anti-Aircraft Artillery
AAM	Air to Air Missile
ADI	Attitude Direction Indicator
AGL	Above Ground Level Altitude
AMRAAM	Advanced Medium Range Air to Air Missile
AOA	Angle of Attack
ASE	Allowable Steering Error

B

BST	Boresight Mode
-----	----------------

C

CAP	Combat Air Patrol
CDI	Course Deviation Indicator
CIC	Close In Combat

D

DEG	Degrees
-----	---------

E

F

FITE	Fusion Interfaces for Tactical Environments Laboratory
FOV	Field Of View
FPM	Feet Per Minute

G

GCAS	Ground Collision Avoidance System
------	-----------------------------------

H

HDD	Head Down Display
HMD	Helmet Mounted Display
HOTAS	Hands On Throttle And Stick
HSI	Horizontal Situation Indicator
HUD	Head Up Display

I

IR	Infra Red
----	-----------

Appendix J. (continued).

J

K

KCAS	Knots Calibrated Air Speed
KIAS	Knots Indicated Air Speed
KTAS	Knots True Air Speed

L

LCD	Liquid Crystal Display
LCOS	Lead Computing Optical Sight
LOS	Line Of Sight

M

MRM	Medium Range Missile
MSL	Mean altitude above Sea Level

N

NM	Nautical Mile
----	---------------

O

OTW	Out The Window display
-----	------------------------

P

PD	Pulse-Doppler
PDT	Primary Designated Target
POM	Plane Of Maneuver

Q

R

RWR	Radar Warning Receiver
RWS	Range While Search

S

SA	Situation Awareness
SAM	Surface to Air Missile
SRM	Short Range Missile
SSI	Systems Status Indicator
SSL	Sleable Scan Lock
STT	Single Target Track

Appendix J. (continued).

T

TAA	Target Aspect Angle
TAS	True Air Speed
TD	Target Designator
TDI	Target Direction Indicator
TID	Target Identification System
TTA	Time To Active
TTG	Time To Go
TWS	Track While Scan

U

V

VSD	Vertical Situation Display
VSL	Vertical Scan Lock

W

X

Y

Z

1.0 BACKGROUND AND DESCRIPTION

The Fusion Interfaces for Tactical Environments Laboratory (FITE Lab) is a facility of the Armstrong Laboratory at Wright-Patterson AFB intended for the purpose of investigating the human factors aspects of new display technologies as they relate to the fighter cockpit. The intent is to develop and evaluate the effectiveness of various display techniques with a view toward improving the fighter pilot's performance in the air-to-air tactical environment.

The evaluation strategy is to present experienced fighter pilots with two simulated fighter cockpits, one ("Conventional") representative of today's typical controls and displays, and the other ("Candidate") which employs a number of unconventional display technologies, methods, and techniques intended to improve the pilot's interface with his aircraft and its systems. Numerous simulated air-combat scenarios will be performed employing each cockpit design, measurements will be taken, and pilot impressions will be recorded to assess the impact and effectiveness of each Candidate display technique.

The FITE Lab cockpit includes a simulated F-16 shell, and is fitted with an F-16C throttle and sidestick controller. This is a fixed-base simulator (see Figure 1) is situated in a small cubical enclosure measuring approximately twelve (12) ft on a side (Figure 1). Out-the-Window (OTW) views of ground features, clouds, other aircraft, etc., are projected on three walls and the ceiling. All system controls accessible to the pilot are situated on the stick and throttle. Most controls not relevant to the air-combat task are automated or eliminated. The simulation is controlled from computer stations located in an adjacent area. Computing power for the simulation and all the displays is provided by twenty-three (23) networked IBM-compatible 80486/33MHz computers. Displays available, in addition to the OTW projection, include a Head-Down Display (HDD), a Head-Up Display (HUD), a Helmet Mounted Display (HMD), a 3-D sound system, and a haptic (tactile) display system.

Also integral to the system are two (2) Auxiliary Stations that can be manned by "threat" pilots. These stations supplement the capability of the FITE Lab to generate "computerized" threats, providing additional realism to simulated air-combat scenarios.

1.1 Flight Model

The computerized flight model employed by FITE Lab for the evaluation cockpit is intended to approximate the performance of an F-15E fighter, while the flight model installed for the threat stations is representative of an F-16. The "feel" of the flight control system of the threat stations is not currently representative of any fighter, but is intended only to provide reasonable control capability for the threat pilots. However, the feel of the flight control system in the evaluation cockpit is determined by the programming of the McFadden control loader. Currently the control system is programmed only to provide reasonable control characteristics for a current fighter aircraft. The control systems and characteristics for the two cockpits are identical.

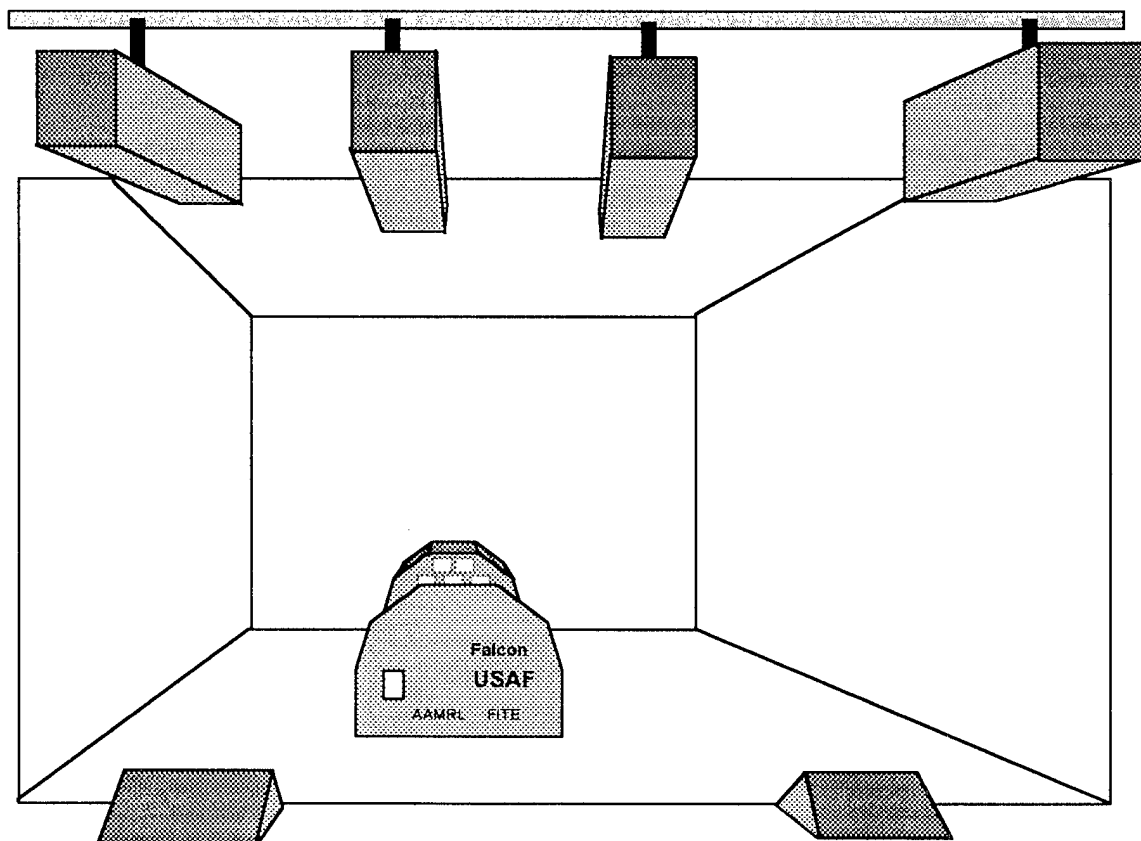


Figure 1. Dome Projection Room

1.2 Weapon Simulations

1.2.1 Gun

The gun simulation is an extremely simplified model of a 20mm Gatling gun, with a 6,000 round/min rate of fire. Initial ammunition loadout is 600 rounds.

The ballistic model tracks individual bullets in flight, but assumes no deceleration of the projectile and zero gravity drop. Essentially, the gun fires slow-speed laser beams. The gunsight display compensates for these factors and, due to the dynamics of the air-combat environment, the simplifications are generally not noticeable. Maximum effective range of the gun is set to 2,000 ft. Projectile flight paths can be assessed to some degree by observing the tracers displayed by the OTW display.

1.2.2 Missiles

Two classes of air-to-air missiles (AAMs) are currently modeled in FITE Lab: a radar-guided Medium-Range Missile (MRM), and an infrared-guided (IR) Short-Range Missile (SRM). The loadout is four (4) of each type weapon.

The models of both these AAMs are relatively simple, but do generate fairly realistic flight profiles and incorporate typical guidance characteristics and limitations that might be expected of such weapons in operational use today. Although not intended to duplicate the performance of any specific real-world weapon, in general the MRM may be considered to be representative of an Advanced Medium Range Air-to-Air Missile (AMRAAM), while the SRM is more typical of the Sidewinder class of AAM. The SRM range is five miles and the MRM range is 20 miles. Both the SRM and the MRM go active after 12 miles.

2.0 SENSOR MODELS

2.1 Radar

The radar model employed by FITE Lab is a highly simplified functional simulation of a modern pulse-Doppler (PD) air-to-air radar with Track-While-Scan (TWS) capability. The pilot has the option to select between 10, 20, 40, 80, and 160 NM range scales in these modes. Azimuth selections are ± 10 , ± 30 , and ± 60 deg, while the antenna may be rotated up or down 60 deg from level. Elevation bar options include 1-, 2-, 4-, and 8-bar scans.

Two radar versions are currently implemented: the Conventional and the Candidate. In actuality, the basic radar models are the same for each version, but the displays are different and there are some variations in the modes available for each. Both the Conventional and Candidate models provide TWS, Single-Target Track (STT), and Close-In Combat (CIC) modes. In addition, the Conventional model provides a Range-While-Search (RWS) mode.

CIC mode includes a number of options for facilitating radar locks in short-range, highly dynamic combat situations. These include Boresight (BST), Sleuable Scan Lock (SSL), Vertical Scan Lock (VSL). In addition, the Candidate model provides the capability to control the radar with the pilot's helmet in HMD mode. All CIC modes are effective only within ten (10) NM range.

BST mode generally provides the quickest lock on a target positioned within a capture ("hot") box of about ± 2 -deg displayed in the center of the HUD. VSL mode searches ± 60 -10 deg vertically, and approximately ± 5 deg in azimuth relative to aircraft heading, and is useful in obtaining locks on targets near the "lift vector" of the aircraft. SSL mode searches ± 30 deg in azimuth relative to the aircraft's nose and ± 12.5 deg in elevation relative to the horizon. The center of this search pattern is selectable discretely as 30 deg left or right of the nose, and straight ahead. In addition, the center of the elevation scan is adjustable continuously within the range of ± 30 deg relative to the horizon. HMD mode, available only with the Candidate model, is analogous to the HUD BST mode, except the ± 2 -deg hot box is centered in the HMD rather than in the HUD. In general, the time required for lock is dependent on the size of the scan volume selected and the proximity of the target to the center of the scan pattern. BST and HMD modes normally provide the quickest locks, followed by VSL and SSL.

RWS mode, available only with the Conventional model, provides a search-only capability representative of the search modes of typical current air-to-air radars. This mode is useful for early target detection and provides the most accurate target position in range and azimuth. Contacts are represented by small rectangular blocks, and round target-history "dots" are provided to aid in visualizing target movement. RWS mode is also indicated by a small "R" in the upper left corner of the radar display between the digital readout of upper and lower bounds of the radar's altitude coverage.

TWS mode provides the capability to maintain "track files" on multiple targets simultaneously, along with information on target speed, altitude, course, and, in conjunction with the Target Identification (TID) System described below, information on the class and type of target. This mode is useful in maintaining situational awareness (SA) in a multi-target environment but, since TWS displays only track files, not contacts, target detection/display will be delayed slightly over that possible with RWS. Generally, this delay is about two radar frames. In this case, a frame is the time the radar takes to complete its complete search pattern, and depends on the selected azimuth limits and elevation bars. Two frames could be as little as about 0.5 secs in ± 10 deg azimuth/1-bar to about 24 secs in ± 60 deg azimuth/8-bar. In addition, when target returns fade while in TWS, target position displayed is updated through extrapolation for some period of time (about 2 frames) before the pilot receives any indication. After two frames without target returns, the displayed target will begin to blink to

Appendix J. (continued).

indicate extrapolation. If the target is not detected within an additional two frames, the target display disappears. So extrapolated targets with a large error factor may be displayed for some time.

STT mode may be entered manually from both RWS and TWS, or automatically from any CIC mode. The capabilities and information available in STT mode are identical regardless of how the mode is entered. STT mode provides the greatest possible accuracy and timeliness of information on a single target.

Fighter-type targets are typically detected and displayed in either search or track modes (i.e., RWS, TWS, STT) at about 40 NM. Somewhat shorter ranges are typical in severe look-down situations.

2.2 Radar Warning Receiver (RWR)

Except for the displays, the RWR model is identical in both the Conventional and Candidate versions. This is a highly simplified simulation, intended to represent typical performance capabilities and limitations of current operational RWR systems. Azimuth accuracy of the RWR system is about ± 5 deg. The range of RWR contacts is displayed relative to assumed enemy weapons maximum ranges in the Conventional version, and in nautical miles in the Candidate version. Range resolution in either case is approximately $\pm 20\%$. Distinctions are made in the display between various radar types [i.e., threat fighter, friendly fighter, range-only, AAM, surface-to-air missile (SAM), anti-aircraft artillery (AAA)], and operating modes [i.e., search or track]. Currently only air-to-air threats are programmed. Typical detection ranges for the RWR system are 30 NM for a target operating its radar in STT, and vary according to the target radar's scan-rate/azimuth-width selection in RWS and TWS. RWR detection may be expected at about 20 NM in ± 10 -deg sweep, 6 NM in ± 30 -deg sweep, and about 3 NM in ± 60 -deg sweep.

2.3 Target Identification (TID) system

The TID system model implemented by the FITE Lab is a highly simplified simulation intended to represent the typical current capabilities of both cooperative (transponder-based) and non-cooperative (radar-signature-based) target identification and recognition systems. Operation of the system is automatic and capabilities are identical in both the Conventional and Candidate versions, but the display techniques vary between versions.

The TID system is operational in either TWS or STT radar modes. Assuming the target has an operating transponder, classification (i.e., friendly or hostile) can be expected within a few seconds of establishing a track file (TWS) or lock (STT) out to the limits of the radar's acquisition capability. Identification (i.e., type) typically takes somewhat longer and is dependent on the range and aspect of the target.

2.4 Ground Collision Avoidance System Symbolology (GCAS)

A GCAS is available only in the Candidate fighter model. (However, ground proximity information is available in the Conventional fighter model using the altimeter.) The purpose of GCAS system is to sense when immediate pilot action is required to avoid ground collision and to provide cues and displays to assist in recovering the aircraft from hazardous conditions.

The GCAS monitors the aircraft's height above the ground, descent rate, dive angle, airspeed, and bank angle to calculate an alert altitude. An alert is calculated to give the pilot a minimum of four (4) secs reaction time to begin recovery. The assumed recovery maneuver used in the GCAS calculations is a maximum of 4Gs or half the current load-factor capability of the aircraft, whichever is less. Additional alert time is provided based on bank angle and airspeed to allow for time required to roll the aircraft to a wings-level attitude to begin recovery.

Appendix J. (continued).

GCAS information is displayed on all visual and audio displays. The initial GCAS alert is signaled by all the LCDs of the HDD flashing red, and the ringing of a "doorbell," localized so that it appears to emanate from the direction of the ground. Simultaneously, a large arrow is superimposed on the HUD, HMD, and center LCD to indicate the vertical "UP" direction as an aid in recovering the aircraft to an upright attitude. In addition to the "Up Arrow," a pair of semi-circular brackets is displayed at the top and bottom of the HUD, HMD, and center LCD which move toward the center of the display at a rate proportional to aircraft closure with the ground. These brackets are calculated to meet at the center of each display on ground impact.

Following the first 4 secs of alert, the doorbell audio warning changes to a siren (also localized to emanate from the ground), increasing in both pitch and volume with decreasing height aircraft above the ground. All GCAS displays are eliminated as soon as recovery proceeds to the point at which alert conditions are no longer met.

3.0 DISPLAYS

3.1 Out-the-Window (OTW) Display

OTW views are projected on three walls and the ceiling of the simulator cubicle by six (6) monochrome black-and-white projectors situated behind the cockpit. The rear of the cubicle is open. OTW field-of-view (FOV) is approximately +/- 130 deg left and right, down 30 deg, and up 90 deg.

3.2 Head-Up Display (HUD)

The HUD is simulated by a monochrome green projection on the front wall of the cubical directly ahead of the cockpit. This display encompasses approximately a 20x20-deg FOV.

3.3 Head-Down Display (HDD)

The HDD consists of six (6) 3.5" x 4.5" color liquid-crystal displays (LCDs) employing a 1,024-by-768 resolution, refreshed at a 30Hz rate. Information may be arranged on these LCDs to simulate individual instruments or displays, or spread over the entire group of LCDs to simulate the availability of a full-panel large-screen display.

3.4 Helmet-Mounted Display (HMD)

The HMD is a Kaiser Agile Eye system that tracks pilot head movement, position, and orientation through electromagnetic sensors mounted on the helmet and the cockpit structure. Information similar to that presented on the HUD may be projected on the pilot's visor. The monocular HMD FOV is approximately 20x20 deg.

An effort has been made to simulate an infinite focal distance for the HMD. Since the OTW display is not an infinite distance from the pilot's position, however, and the minimum focal range of the HMD is greater than the distance to the OTW display, the goal of matching the HMD focal distance to the OTW display can not be achieved exactly. This is a recognized limitation of the FITE Lab.

3.5 3-Dimensional (3-D) Audio System

The 3-D sound system is employed to replicate environmental noises, system alerts, warning tones, etc., localized in any desired direction from the pilot's head. Tone generation and speech synthesis are performed by a Sound Blaster Pro system and the auditory localizer, also an off-the-shelf system, is a Convolvotron.

3.6 Haptic Display

The Haptic Display consists of a McFadden hydraulic control loader driving the stick and rudder pedals. This system may be programmed to provide a wide variety of force and position feedback to the pilot to replicate selected flight-control characteristics or enhance the "feel" of the simulator.

4.0 CONTROLS AND DISPLAYS FORMAT

4.1 Aircraft/Systems Controls

Aircraft controls are identical F-16C controls for both the Conventional and Candidate models, and include a throttle, sidestick controller, and rudder pedals. See Figures 2 thru 5 for Candidate and Conventional stick and throttles diagrams. Control characteristics are currently identical for both models.

The throttle moves in a range from idle to full afterburner (MAX), with a light afterburner detent denoting the limit of the full military (MIL) power range. Afterburner is selected by rotating the throttle outboard and continuing to advance past the MIL position. The throttle cannot be moved to the OFF position.

Aircraft control functions are also provided by various switches on the stick and throttle. The speedbrake control is a sliding switch located on the throttle marked "SPD BRK." This control functions normally as in an F-16, with the forward position fully closing the speedbrakes. Holding this switch in the rear position opens the speedbrakes, which stop their movement when the switch is released. This switch is spring loaded to return to center when released from a rearward (open) actuation. Full actuation of the speedbrakes from closed to full open, and vice versa, takes about two (2) secs. In the Conventional model, a speedbrake status indicator is provided on the Systems Status Indicator of the instrument panel showing "CLOSED" when fully closed, "TRANSIT" when in transit, and "OPEN" when fully open. In addition, there is a "SPDBRK" indication near the bottom of the HUD whenever the speedbrake is not fully closed.

In the Candidate model, speedbrake status is also indicated on the Systems Status Indicator as well as on the HUD and HMD. On the Systems Status Indicator of the HDD, speedbrake status is indicated by the color of rectangular blocks located on the outline of the horizontal stabilizer. These blocks are green when the speedbrakes are fully closed, yellow when in transit, and blue when fully open. Whenever the speedbrakes are not fully closed, there is a "SPDBRK" indication on the HUD and HMD just above the heading indicator near the bottom of each display.

Trim control for roll and pitch is provided by the usual "coolie hat" switch located on the sidestick controller. There is no manual rudder trim.

Chaff and flare dispensing are controlled by the Thumb Slider switch on the stick just under the Pickle Button. All expendables dispensing is manual, with two (2) bundles of chaff dispensed with each forward actuation of the Thumb Slider and one (1) flare dispensed with each rearward actuation. Total expendables capacity is thirty (30) chaff bundles and fifteen (15) decoy flares.

4.2 Visual Displays and Controls, Conventional Model

As described above, visual displays available to the FITE Lab include the HDD, HUD, and, in the Candidate model only, the HMD. It should be kept in mind that instrumentation provided is limited by many factors, and is sparse by normal cockpit standards. As the primary focus of FITE Lab is pilot cockpit interfaces in the air-to-air combat environment, priority has been given to that instrumentation required for daylight, visual air combat. Therefore, for instance, instrumentation may be inadequate for precise instrument flying.

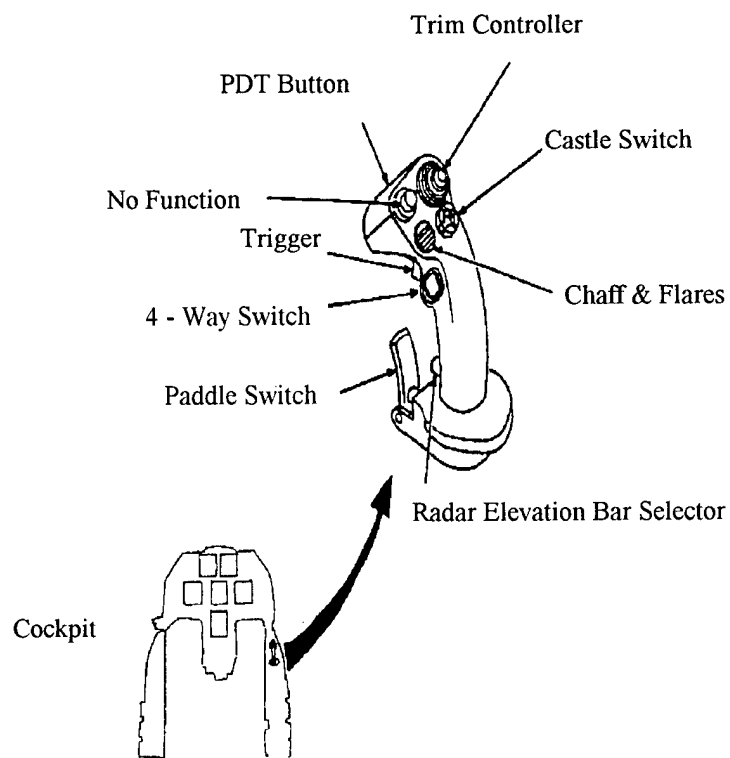


Figure 2. Experimental Cockpit - Conventional Side-Stick

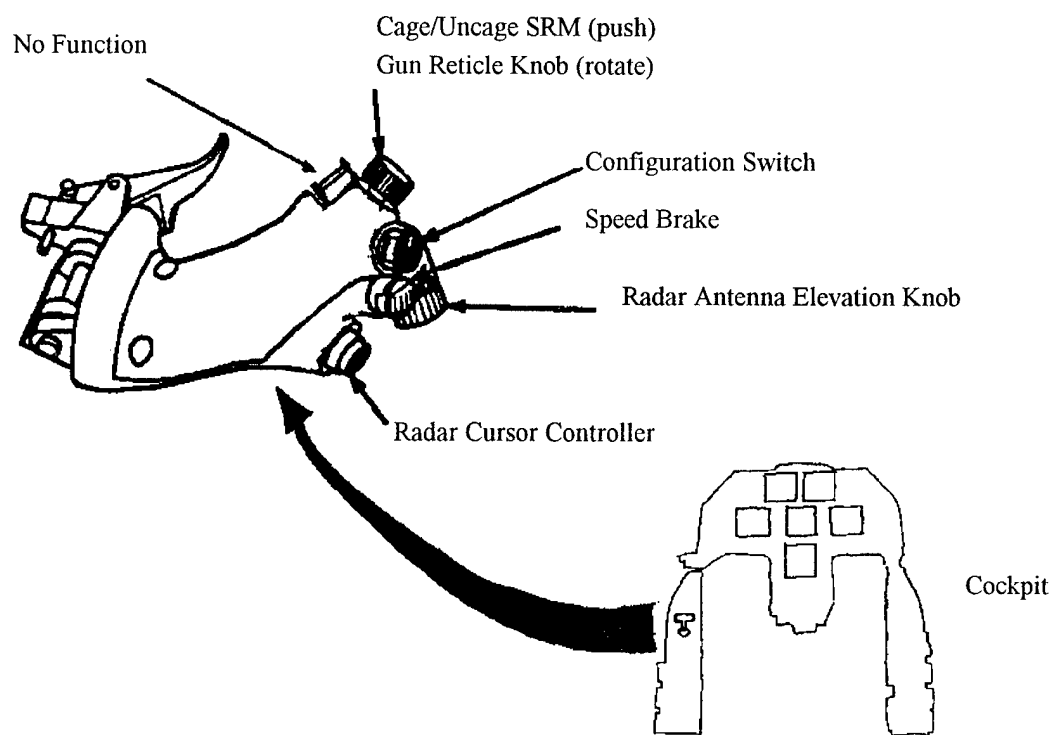


Figure 3. Experimental Cockpit - Conventional Throttle

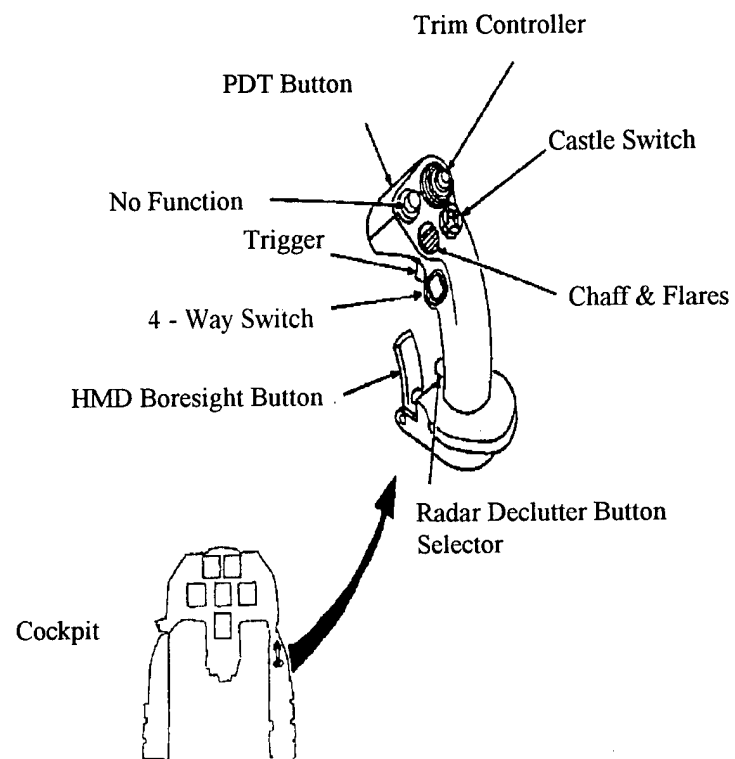


Figure 4. Experimental Cockpit - Candidate Side-Stick

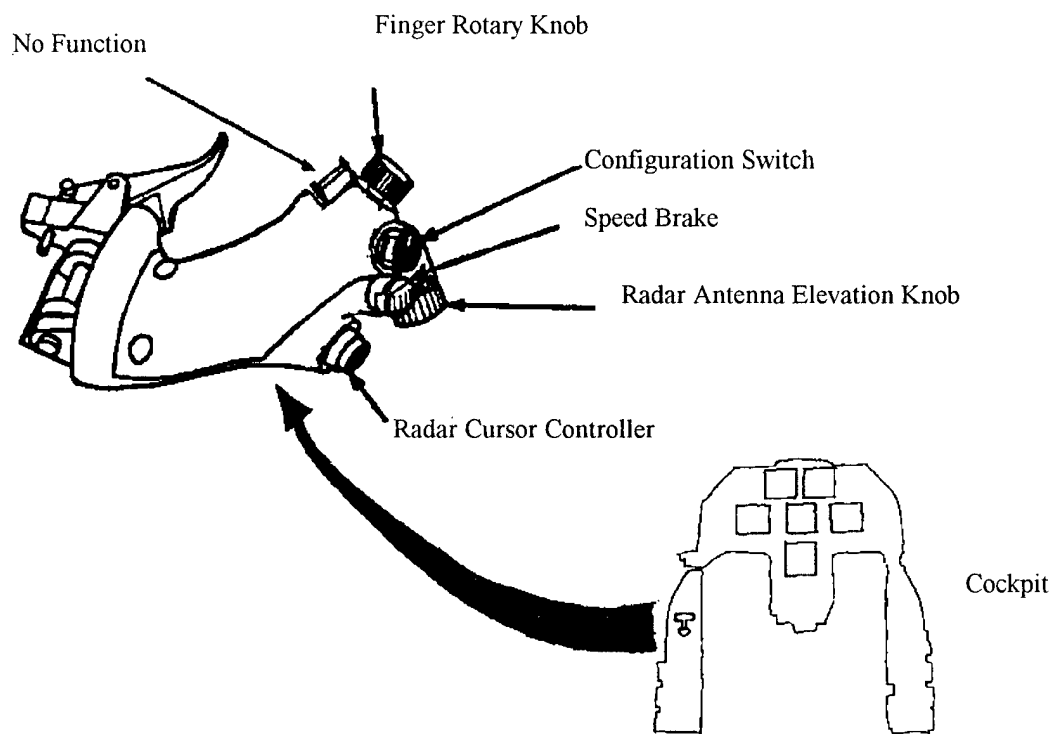


Figure 5. Experimental Cockpit - Candidate Throttle

Appendix J. (continued).

In the Conventional model, each of the six (6) color LCDs (see Figure 6) that comprise the HDD represents a separate instrument or display that might be expected in a current fighter cockpit. The upper left LCD provides a conventional air-to-air radar B-scope display, while the upper right LCD represents a conventional RWR display. The left LCD of the center row depicts an airspeed indicator, the center LCD shows an Attitude Direction Indicator (ADI), and the right center LCD provides an altimeter. The lower LCD has dual functions. Its default presentation is a Systems Status Indicator (SSI), but, alternatively, it can display a Horizontal Situation Indicator (HSI) for navigation purposes. Selection between these two formats is controlled by rearward actuation of the Castle Switch, located on the stick just below the trim control (Coolie Hat).

The airspeed indicator, altimeter, and ADI are all very conventional formats and should require no explanation for an experienced pilot. Likewise, the HSI depicts the usual compass rose with the "Own Aircraft" symbol in the center. Readouts are provided for selected course in the upper right corner and distance (NM) from the selected station or waypoint in the upper left. A vertical Course Deviation Indicator (CDI) needle indicates deviation from the selected course in both direction and magnitude, with full CDI deflection representing 10 deg of deviation. A Course Arrow indicates the magnetic course to the selected station or waypoint. There is no provision for pilot selection of the reference station, waypoint, or course; these are software controlled.

The SSI is a composite display intended to provide, in one format, required information that might typically be provided by several different displays around the cockpit. This information includes weapon selected and number of each type available, fuel status, speedbrake status, and expendables available. There are no engine instruments implemented by FITE Lab.

In the Conventional model, weapon selection is indicated on the SSI by an alphanumeric readout at the top center of the display. This readout consists of a letter (i.e., G, S, or M) indicating the weapons mode (i.e., GUNS, SRM, or MRM, respectively), followed by a number denoting the number of rounds currently available for that weapon. Gun ammunition is displayed in "tens of rounds" to the nearest ten. A full weapons loadout consists of 600 cannon rounds, four (4) SRMs, and four (4) MRMs for both models.

At the top left of the SSI is an indication of chaff bundles remaining. This is also an alphanumeric readout composed of the word "CHAFF" with the number of chaff bundles available underneath. On the right side of the display near the top is a similar indication of flares remaining, indicated by "FLARES" with the number of flares available underneath. At the bottom center of the SSI is the speedbrake status indicator. This readout simply displays the words "CLOSED," "TRANSIT," or "OPEN" to indicate speedbrake status.

The center of the SSI is dominated by a Fuel Quantity Indicator. This display is modeled on the F-16 Fuel Quantity Indicator and consists of a round dial, two (2) needles, and a digital totalizer readout. The digital totalizer window indicates the total usable fuel quantity available in the aircraft to the nearest 100 lbs. A full internal load is 13,400 lbs. The analog dial is labelled from zero to 8,000 lbs in hundreds of lbs. The simulated fuel system is divided into Forward/Right and Left/Aft portions, similar to the F-16 arrangement. Each internal wing tank has a capacity of 3,000 lbs and the fuselage tankage is 7,400 lbs, divided approximately equally between Forward and Aft tanks. The two (2) needles on the Fuel Quantity Indicator display the quantity in each of the two sections of the fuel quantity system. The needle labelled "F/R" indicates only fuel remaining in the forward fuselage tank and in the right wing tank. The "A/L" needle indicates fuel remaining in the aft fuselage tank and left wing tank. Total fuel in the combined wing tanks can be calculated by subtracting the total of the two needles from the totalizer value. There are no external fuel tanks simulated.

Operation of the fuel quantity system is fully automatic and no controls are associated with the system. In normal operation, internal wing fuel is transferred into the forward fuselage tank as fuel is burned, keeping this tank full. The forward fuselage tank, in turn, feeds the aft fuselage tank, keeping it full. Normal operation of the fuel quantity system is indicated by the totalizer value and

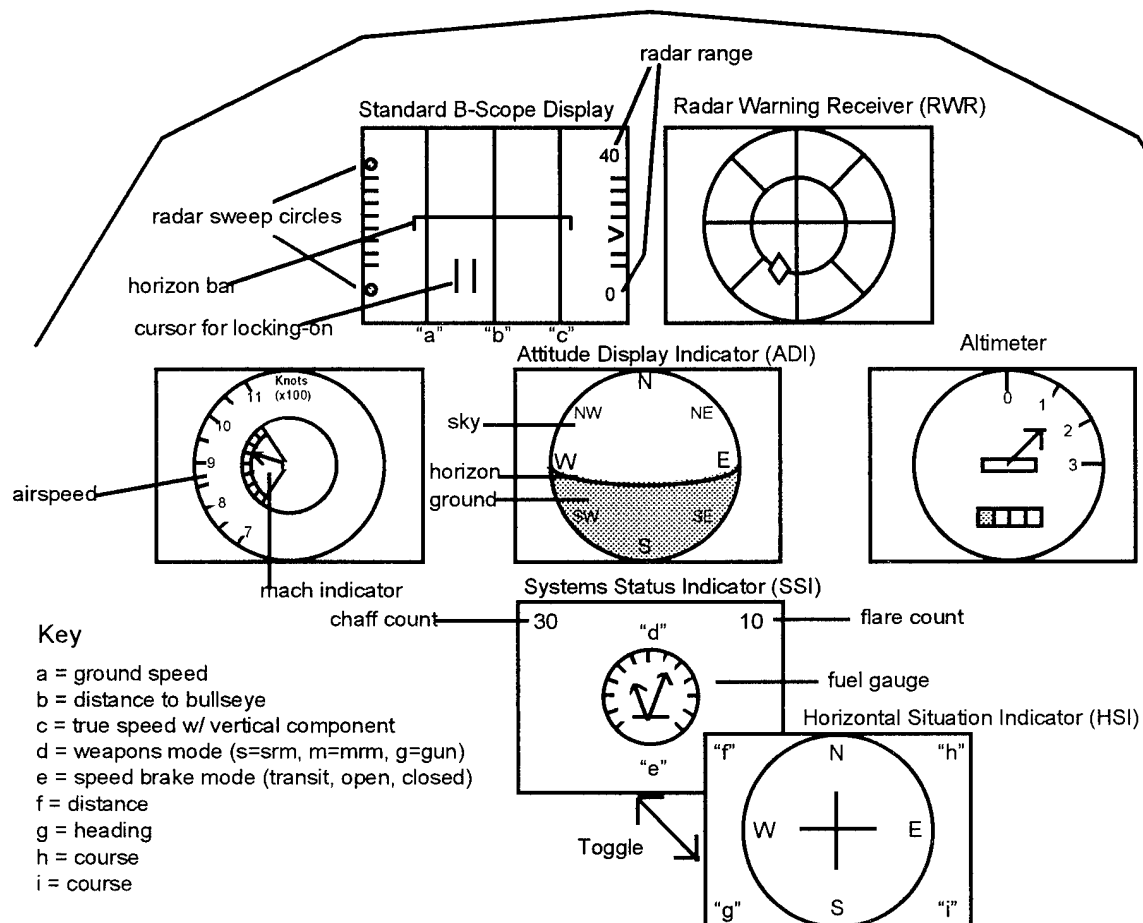


Figure 6. Conventional Cockpit Interface.

both needles decreasing together, with the sum of the needle readings roughly equal to the digital totalizer reading. After completion of wing tank transfer, the F/R needle should continue to decrease to zero while the A/L needle remains steady at approximately 3,700 lbs. Once the forward fuselage tank is empty, the A/L needle should again begin to decrease. Several fuel transfer abnormalities may be programmed for evaluation purposes. The pilot is alerted to these conditions by a "FUEL TRANSFER" aural warning.

For each mission with the Conventional model, a JOKER fuel state is established, based on the distance of the operating area from the home air base. No indication of JOKER fuel quantity is provided by FITE Lab displays until this fuel state is reached. At this time, a "JOKER, JOKER" voice warning is sounded.

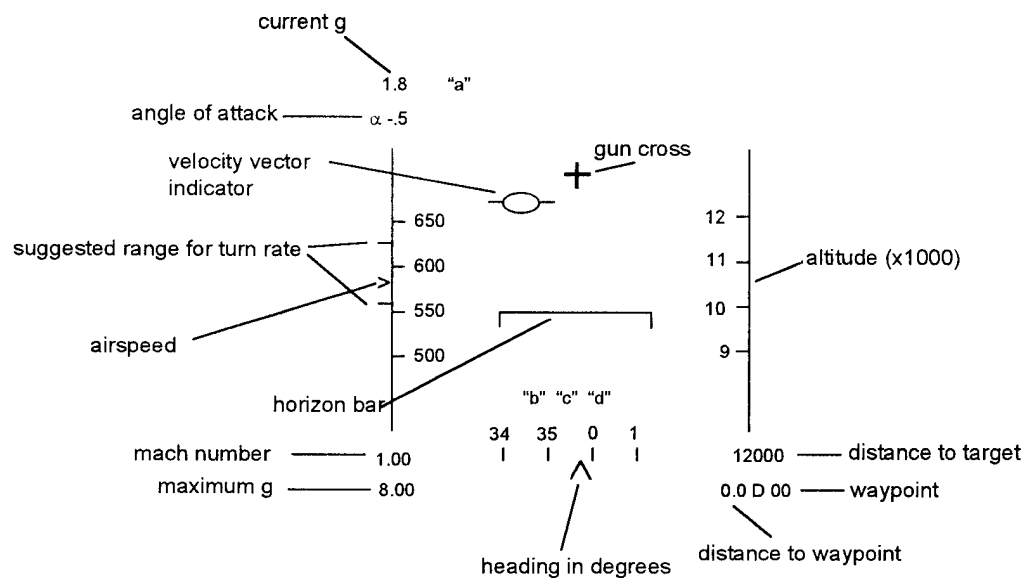
In the Conventional model, the RWR display is located in the upper right LCD of the HDD. Operation of the RWR system is fully automatic and there are no controls associated with it. The display comprises a set of three (3) concentric circles, a vertical and a horizontal reticle line, and tick marks around the periphery of the outer ring to denote azimuth relative to the nose of the aircraft; assumed to be located at the center of the display, pointed at the indicator's 12:00 position. Azimuth tick marks are arranged at 15-deg intervals. Symbols appear on the display indicating the approximate azimuth and range of the detected radar emitter. Range placement of threat symbols is based on signal strength and an assumed maximum threat range. Signals detected from threats assumed to be outside their maximum threat range will appear inside the outermost ring of the indicator, but outside the second (threat) ring. As the signal increases in strength, the symbol will move toward the center of the display, crossing the threat ring at its assumed maximum threat range.

Currently, only air-to-air threats are implemented in the RWR system. Possible symbols include an AIRCRAFT, denoting a pulse-type air-to-air radar and a WINGFORM indicating a pulse-Doppler (PD) air-to-air radar. In addition, an "F" may be superimposed over either of these symbols to indicate a friendly-type radar. Typically, bomber radars will be indicated by the AIRCRAFT symbol and fighters by the WINGFORM. Either symbol may be accompanied by an "F." In addition to these symbols denoting aircraft radars, active radar-guided AAMs locked onto the fighter will be indicated by an "A" with three (3) dots underneath (A, 3-DOT symbol).

Whenever a new emitter symbol is displayed on the RWR scope there is an audio tone alert, consisting of eight (8) high-pitched "beeps," heard in the pilot's headset. This tone is then replaced by another tone of lower volume representing the pulse-repetition frequency (PRF) of the detected radar. The higher the PRF, the higher the pitch of this tone. The PRF tone may be intermittent, since it is only generated when the detected radar is actually pointed at the fighter. The symbol, however, remains steady for up to five (5) seconds after the last signal detection.

An automatic prioritizing algorithm is functional in the Conventional model RWR system, by which targets are prioritized according to their assumed threat. The signal judged to represent the highest threat will be placed in a PRIORITY DIAMOND symbol. With only one non-friendly signal detected, it will be designated the highest priority threat. With multiple detections, contacts are ranked on the basis of type and range. Highest ranked are AAMs in order of range, followed by non-friendly PD emitters inside the threat ring in order of range, non-friendly pulse-type emitters inside the threat ring in order of range, then the same ordering of non-friendly PD and pulse-type threats detected outside the threat ring. No threat prioritization algorithm is currently implemented in the Candidate model.

The HUD in the Conventional model (see Figure 7) provides flight parameters, navigation, and weapon system information in a format very typical of current fighter HUDs in "declutter mode." A heading scale is positioned near the bottom of the display, and airspeed (KCAS) and barometric altitude tapes are arranged vertically on the left and right sides of the HUD, respectively. A conventional horizon line and Flight Path Marker (FPM) are also provided, but no pitch/dive scale is depicted. On the left side above the airspeed scale are digital readouts of instantaneous load factor



Key

a = weapons mode (g=gun, srm=short range missile, mrm=medium range missile)
 b = speed brake indicator
 c = chaff count
 d = flare count

Figure 7. Conventional Cockpit Head Up Display

Appendix J. (continued).

(G) and AOA in degrees. At the lower right, below the altitude scale, is waypoint data in the format ____D__ (read, as in the F-16, as ____ NM from Destination ____).

HUD weapons information includes a Gun Cross in the upper center indicating the boresight of the gun. In the far upper left of the HUD is an alphanumeric weapon selection and quantity indication comprising a letter, followed by a number. The letters are G (Gun), S (SRM), and M (MRM). The numbers indicate the quantity of each aboard, i.e., 1-4 for missiles and 1-60 for the gun. Each unit for the gun represents ten rounds of ammunition remaining; the full load is 600 rounds. When a weapon is selected but none of that type remain, the number reads zero and blinks. Below the altimeter scale on the left side of the HUD is a digital readout of Mach number, and immediately below the Mach indication is a digital reading of the maximum load factor (G) attained during the mission. This indicator is automatically reset to zero at the beginning of each mission.

With a radar lock (STT) or a track file in TWS, the line-of-sight (LOS) to the locked target (STT) or Primary Designated Target (PDT) is indicated by a Target Designator (TD) "box." At the edge of the TD box is a small triangle pointing toward the center of the box indicating the Target Aspect Angle (TAA). This TAA indicator is interpreted as though it represents the target when viewed from above. So when the triangle is at the top of the TD box pointing downward, the indicated TAA is 180 deg (head-on). Likewise, when the triangle is on the right side of the TD box pointing to the left, the indication is 90 deg left TAA. When the TD box is outside the FOV of the HUD, it disappears and a Target Direction Indicator (TDI) line is drawn from the gun cross toward the LOS to the target. A number also appears near the end of this TDI line indicating the number of degrees the target bears from boresight. The TAA triangle remains displayed near the end of the TDI line. When missiles are selected, an Allowable Steering Error (ASE) circle is also displayed in the center of the HUD. As explained below in the Weapons Employment discussion, the ASE circle represents the approximate aiming error allowed for successful employment of the AAM selected. The ASE circle is fixed in size: 65 mils radius for the SRM and 131 mils for the MRM. Around the edge of the ASE circle is displayed a second TAA triangle, interpreted as described above, whenever there is a PDT or STT.

In the lower right corner of the HUD, below the altitude tape and above the waypoint data, is a digital readout of range to the tracked target (STT) or the PDT in TWS. This range is displayed in NM outside 3 NM, and in feet, to the nearest hundred inside 3 NM (18,200 ft).

When SRM or MRM is selected, a small diamond is displayed indicating the LOS of the missile's seeker. The diamond is fixed with MRM selected, but is slaved to the radar LOS with SRM selected whenever a target (STT) or PDT (TWS) is available. The size of the seeker diamond also increases whenever the SRM seeker is uncaged and independently tracking a target. See the discussion below on AAM employment.

When GUN is selected and gun ammunition remains, the HUD presents a gunsight display in the form of a Lead Computing Optical Sight (LCOS). The sight consists of a pipper surrounded by a circular reticle. The size of the reticle depends on the radar-lock status. With an STT, the reticle is fixed at a 25-mil radius. Without a radar lock (STT), the size of the reticle is controlled manually by rotation of the Finger Rotary Knob on the top of the throttle. Rotating this knob forward (clockwise) selects a 1,500 ft assumed target range, while rearward rotation selects 700 ft range (as in the F-16). The size of the reticle without a radar track is calculated to match the wingspan of other fighter aircraft displayed in the OTW view when at the selected range. The selected range, or radar range with a STT, is also displayed in the lower right corner of the HUD beneath the altitude tape.

Extending from the gunsight reticle whenever the total acceleration of the aircraft exceeds $\pm 0.5G$ are two lines diverging at a 10-deg total angle which form a "funnel" with its apex at the pipper. This is the Plane-of-Motion (POM) funnel. Bullets fired in a steady-state turn should appear to fall roughly along the centerline of the POM funnel. With a radar track there may also be displayed a Snapshot Arc across the POM funnel at some distance from the reticle. This Arc represents the additional ballistic lead required to compensate for any target drift. Whenever target drift is insignificant, the Snapshot Arc is not displayed. See the discussion of Gun employment below. Whenever the correct placement of the gunsight pipper is outside the HUD FOV, a large "X" is

drawn through the pipper and reticle. The gunsight reticle disappears when gun ammunition is expended.

In Gun mode, there is also an Analog Range Bar displayed around the circumference of the gun reticle with a STT. This Analog Range Bar is a thickened boundary of the reticle extending partially around the circle's circumference, beginning at the top (12:00) position. The Bar extends around the reticle to indicate the target range, with each clock code representing 1,000 ft. Therefore, the 6:00 position indicates 6,000 ft and the total circumference represents 12,000 ft. Without a STT, the analog range bar indicates the manual range selected, i.e., 1,500 or 700 ft. Closure is indicated digitally in knots just to the right of the Gun Cross.

Selection of CIC radar modes is also indicated on the HUD (see Figure 8). A 2-deg square near the center of the HUD denotes the hot box for a radar lock in BST mode. A long vertical line in the center of the HUD indicates VSL mode. SSL mode is indicated by a "horizontal ladder" near the center of the HUD. An "X" positioned on the various legs of the ladder show the position of the center of the SSL scan pattern. When located along the single horizontal line of the ladder, the X denotes the radar is searching level with the horizon (gyro stabilized). Pressure on the cursor Slew Button (on the throttle) moves the X up or down along one of the three (3) vertical "rungs" of the ladder. When positioned at the vertical limits of the ladder, the X indicates the SSL search pattern is centered 30 deg above or below the horizon. Selection of search pattern elevation is continuous with the cursor Slew Button, but azimuth selection relative to the aircraft's nose is in discrete 30-deg steps left, center, or right. Two digital readouts are provided, one above, the other below the center rung of the ladder. The top number gives the top of the SSL scan pattern at a distance of 5 NM in thousands of feet (MSL), while the lower number gives the lower bound of the SSL search pattern at that range.

4.3 Visual Displays and Controls, Candidate Model

This section will describe the differences in the controls and displays of the Candidate model as opposed to the Conventional model outlined above. The visual controls and displays available to the Candidate model are identical to those of the Conventional model except for the addition of the HMD. The display formats, however, may vary widely, with the greatest variation in the HDD.

In the Candidate model, the six (6) color LCDs (see Figure 9) that comprise the HDD are treated as though they formed one large-screen display. In fact, there are plans to replace these LCDs with just such a display when one becomes available to the FITE Lab. Currently, however, there are some obvious limitations and artifacts that must be tolerated when simulating a single large-screen display with six individual LCDs. The most severe of these result from the physical gaps between each display. In most cases, graphics techniques are employed to provide the displayed information in as seamless a manner as possible so that, as an object (for instance a radar target) leaves the bounds of one LCD, it immediately appears on the adjacent LCD with no loss of information. In some cases, however, a choice must be made between lost information and the apparent continuity of lines that transit between multiple LCDs. In most cases, the choice has been made in favor of eliminating lost information, resulting in some distracting linear discontinuities. With some practice, however, the pilot should have little difficulty adjusting to this artifact.

The HDD display in the Candidate model combines two (2) different displays, each with a different perspective, into a single format. Always present is a simulated OTW display with a Horizon Line extending entirely across the limits of the HDD. The background color of the display is light blue above the Horizon Line to represent the sky. Below the Horizon Line is a simulated ground display composed of a light tan background with superimposed rectangular blocks of darker brown. The blocks are arranged into three (3) rows extending from the bottom of the display upward to the Horizon Line, drawn in perspective to provide the illusion of extending into the distance. Whenever the aircraft is in motion, the blocks move from the Horizon Line downward at a rate proportional to ground speed. The apparent size and speed of the brown blocks are also adjusted to reflect height

Cockpit Interfaces: Head-Down Display Radar Symbology

<u>Classification</u>	<u>Color</u>	<u>Shape</u>
Bombers	Red	Equilateral Triangle
Fighters	Red	Isosceles Triangle
Friendly F-15	Green	Circle
Unknown, Neutral	Yellow	Circle (?)

(conventional mode = shape coding only; augmented mode = color and shape)

Radar Warning Receiver (RWR) indicates the direction of incoming radar signals.

Head-Up Display and Helmet-Mounted Display Radar Symbology

- Track-While-Scan: Standard/Default Mode, No symbology

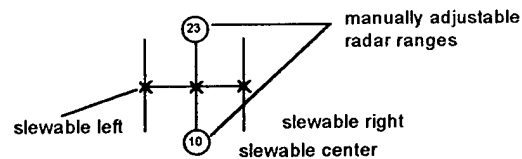
- Vertical Scan



- Boresight Mode



- Slewable Modes



- Helmet-Mounted Display Mode
Used in conjunction with the HMD; thus, allowing one to lock targets by centering the display on the target by moving one's head.



Figure 8. Display Symbology

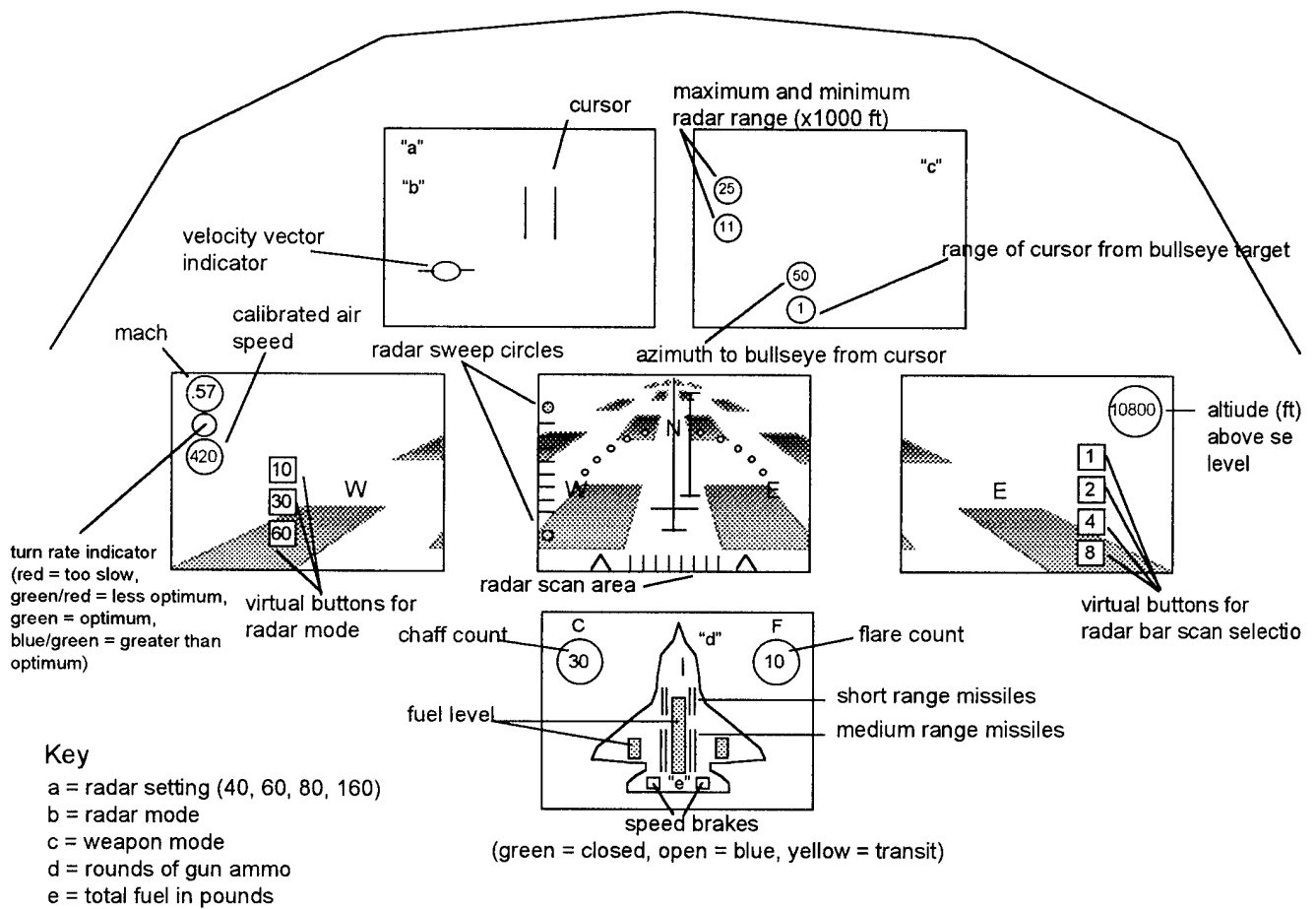


Figure 9. Virtually-Augmented Cockpit Interface

Appendix J. (continued).

above the ground. In effect, these blocks can be considered to be rectangular fields of a given size on the ground. The size of the blocks is scaled so that a single block extends entirely across the HDD when the aircraft is on the ground, giving the pilot a good "feel" for his height above the surface and his rate of descent at low altitudes. Adjustments to block size and speed with altitude are discontinued at 10,000 ft AGL.

Attitude information is conveyed by the Candidate HDD through the position and orientation of the Horizon Line in relation to a FPM, similar to the HUD format. Full displacement of the Horizon Line to the top or bottom of the limits of the HDD represents roughly 45 deg of dive or climb, respectively. At pitch attitudes exceeding these limits the Horizon Line remains "pegged" at the top or bottom of the HDD, but a star-shaped symbol or "tadpole" symbol is displayed to represent the relationship of the velocity vector (FPM) to the pure vertical nose-up, or nose-down attitude, respectively.

A small circular airspeed indicator and altimeter are provided in the lower left and right corners, respectively, of the HDD. The single airspeed indicator needle rotates clockwise with increasing airspeed. There is no digital scale around the circumference of the airspeed indicator, but a digital readout of KCAS (to the nearest 10 KCAS) is positioned below the indicator and a Mach number (to the nearest .01 M) readout is located above the indicator. The airspeed indicator needle revolves completely around the indicator, returning to the 12:00 position, every 100 KCAS.

The displayed color of the airspeed indicator depends on airspeed. The circular dial is divided into halves along the vertical diameter, with the color of the right half of the indicator representing the relation of current airspeed to aircraft corner velocity, and the left half related to sustained turn capability. When airspeed is below the current calculated corner speed, the right half of the indicator will be red. The color of this segment will change to green for speeds at, or above corner speed. The left half of the airspeed indicator has three (3) ranges of color. Whenever airspeed is calculated to be within a range that provides approximately 90 - 95% of optimum sustained turn capability, this segment will be green. At speeds below this range the left hemisphere will be red, and at speeds above this range it will be blue.

The altimeter is a similar indicator combining the functions of an altimeter and a Vertical Speed Indicator (VSI). The single indicator needle revolves clockwise around the indicator with increasing altitude, making a complete revolution and returning to the 12:00 position each thousand feet. A digital readout of altitude (MSL), to the nearest 10 ft, is provided below the altimeter. A VSI caret is also provided, which rotates around the outside of the left hemisphere of the altimeter. When this caret is located at the 9:00 position, vertical speed is zero. A climb is indicated as the caret rotates clockwise and a dive when the caret rotates counterclockwise. The 12:00 position represents a 6,000+ ft/min climb rate, while the 6:00 position denotes a 6,000+ ft/min dive. The color of the altimeter depends on AGL altitude. Above 5,000 AGL the indicator is green, and below that height it is yellow. Below 2,000 ft AGL it blinks red at a 2 Hz rate.

Navigation information is provided on the HDD in a number of ways. An Own Aircraft symbol is displayed in the lower half of the HDD with a line extending from the nose of the symbol upward intersecting a compass rose to indicate aircraft magnetic heading. Various "waypoint" symbols may also be displayed, including a "homeplate" symbol denoting the primary airbase and a "target" symbol (small concentric circles) representing a "bullseye" point. These symbols are positioned at the proper bearing and range, determined by the selected range scale, in relation to the Own Aircraft symbol. Additional artificial features, such as Combat Air Patrol (CAP) patterns and airspace boundaries may also be depicted by various colored lines.

The bottom LCD in the Candidate model is dedicated to an SSI for providing information regarding the status of various aircraft systems. The Candidate SSI takes the form of the silhouette of a generic fighter aircraft and two (2) circular analog gauges, one each for chaff and flare quantity. The Chaff Indicator is located in the upper left portion of the display and is labelled "CHAFF." This indicator is colored green when full and includes a digital chaff quantity indication in the center. As chaff is dispensed, digital indicator counts down the quantity remaining. In addition, the segment of the gauge representing the expended chaff is colored yellow, beginning at the twelve-o'clock position and

Appendix J. (continued).

continuing clockwise around the gauge. Therefore, when half the available chaff capacity is expended, the right hemisphere of the gauge will be yellow and the left hemisphere green. When the quantity reaches zero, the color of the gauge turns red and the quantity remaining reads zero. The Flares Indicator, located in the upper right portion of the display, operates similar to the Chaff Indicator, but is labelled "FLARES."

The SSI fighter silhouette has a number of symbols superimposed to indicate the status of various systems. The number of AAMs loaded is indicated by the number of missile symbols depicted, with the smaller symbols in the forward fuselage area representing SRMs and the larger symbols in the aft fuselage area denoting MRMs available. The particular weapon next in the firing order will be colored blue, the rest green. In the right nose area of the fighter silhouette is the Gun symbol. When GUN mode is selected, the Gun symbol turns blue, otherwise it is green. There is a digital readout of gun rounds remaining, in tens of rounds, just to the right of the Gun symbol. When all gun ammunition is expended, the Gun symbol turns yellow and the zero quantity readout blinks.

The Fuel Quantity System is depicted by three (3) large colored rectangles, one in the center of the fuselage and one in each wing. These rectangles represent the fuselage and internal wing tanks, respectively. When full to capacity, the entire area of a given tank is colored green. As fuel is used or transferred from a tank, the colored area is reduced beginning at the top of the rectangle, so when half full, only the lower half of the tank will be colored green. Digital quantity readouts are also provided for each tank, in hundreds of lbs, as well as a totalizer quantity just aft of the tail of the fighter silhouette.

A red line is drawn across the fuselage tank area indicating the JOKER fuel level, with the JOKER fuel quantity indicated by a digital readout in the aft fuselage tank area. Currently, the JOKER fuel level is preselected and remains constant during the mission. Once fuel quantity reaches JOKER state, the colored area of the fuselage tank representing fuel remaining turns red. There will also be a momentary (5 secs) flashing "JOKER" in the lower center of the HUD and HMD, and a "JOKER, JOKER" voice warning. BINGO calculations and displays are not currently implemented.

Speedbrake status in the Candidate model is indicated by the color of two (2) small rectangles located in the area of the horizontal tail of the fighter silhouette on the SSI. These rectangles are green when the speedbrake is fully retracted, yellow when in transit, and blue when fully deployed.

In the Candidate model, the RWR display is integrated with the radar display on the HDD. As with the Conventional model, the RWR system is fully automatic and has no associated controls. Detected emitters are indicated by colored "fans" extending from near the Own Aircraft symbol along the azimuth of the emitter. The angular width of these fans represents the angular uncertainty in the detected signal, while the length of the fan denotes the system's estimate of emitter range, referencing the radar range scale. The color of the fan indicates whether the emitter is classified as threat or friendly; red denotes a threat and green a friendly emitter. Emitter type is represented by the color pattern of the fan. Doppler radars show a double-hashed pattern, pulse radar fans are single-hashed, and active AAMs generate "polka-dotted" fans. Operating mode of the emitter is indicated by the RWR audio; intermittent audio indicates search or TWS mode, while a steady audio indicates a radar lock. No threat-prioritization system is currently implemented in the Candidate RWR model.

Audio cues for the Candidate RWR system are also identical to those described for the Conventional system. In the Candidate model, however, the audio tones are localized, so that they appear to emanate from the direction of the emitter generating them. Volume is also adjusted to increase as the range to the emitter decreases, with the tones generated by threat emitters being louder than those of friendly emitters.

The HUD in the Candidate model (see Figure 10) is very much the same as described above for the Conventional model with a few additions. In addition, there are a number of marks and carets on the left side of the airspeed tape that provide information related to airspeed. A double-thickness tick mark is positioned to indicate the current value of corner speed, and a longer, thin tick mark indicates the current speed for best sustained turn rate. In addition, the lower limit of the best sustained

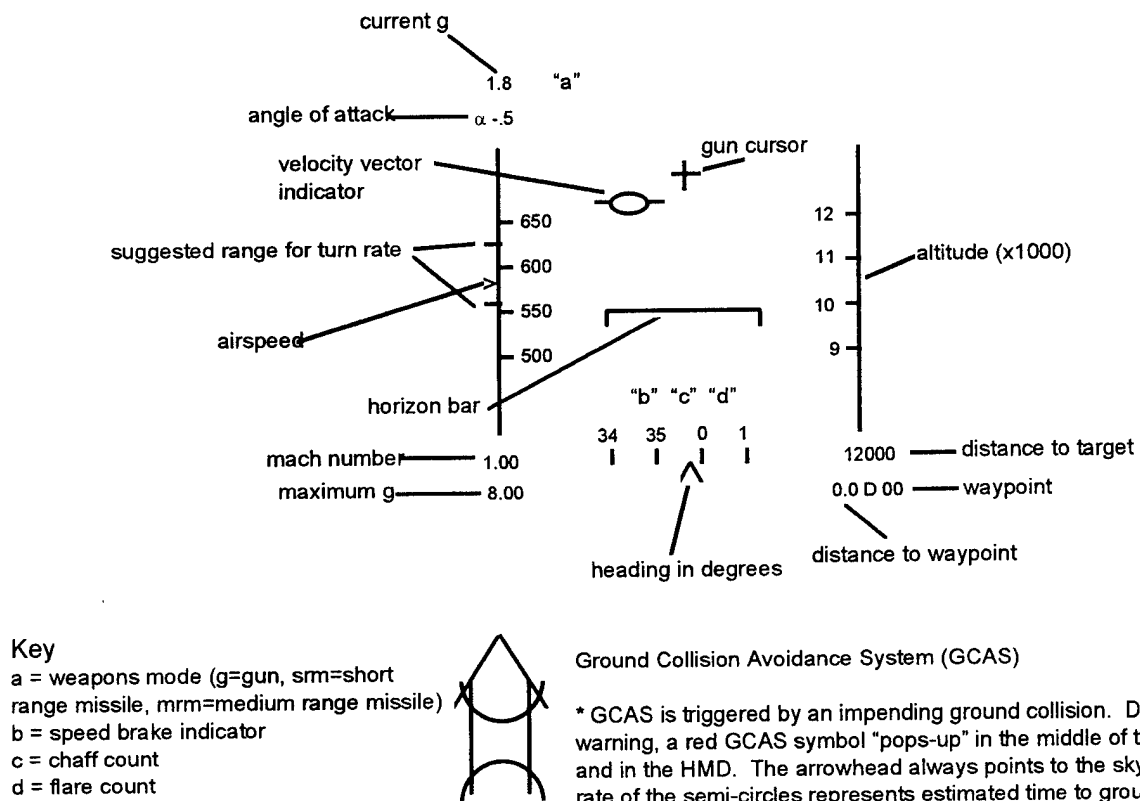


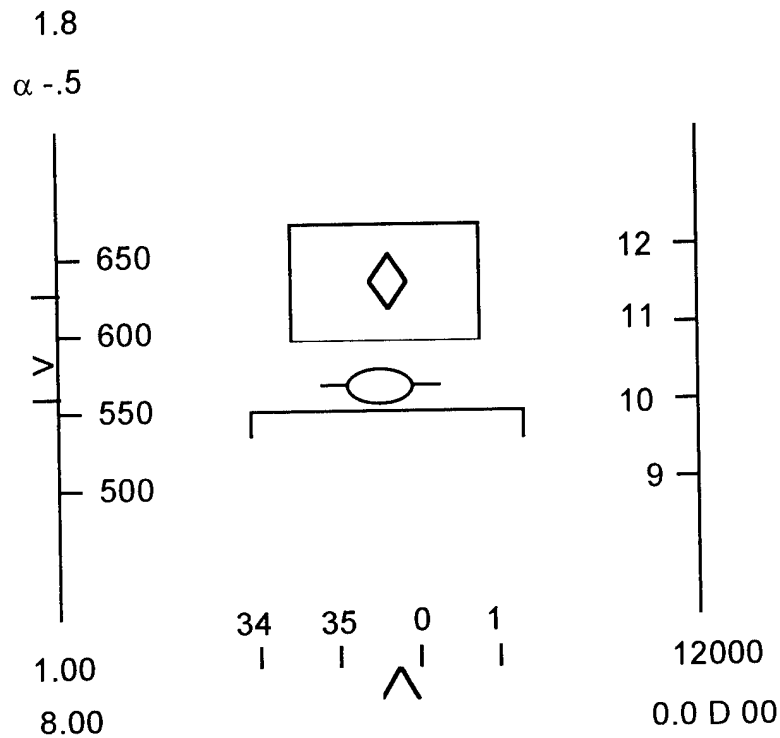
Figure 10. Virtually - Augmented Head - Up Display.

Appendix J. (continued).

maneuver range is indicated by a tick mark with a caret below pointed upward, while the upper limit of this airspeed range is denoted by a similar tick mark and caret above the tick pointed downward. These marks operate in conjunction with the colors of the airspeed indicator as described above.

The HMD used with the Candidate model precisely duplicates the HUD (see Figure 11) format except for a few features. There is normally no Gun Cross depicted in the HMD, nor is there an indication of selection of VSL or SSL CIC radar modes, since selection of HMD mode is exclusive of these options. Instead, there is a 2-deg square positioned in the center of the HMD display to indicate the "hot" region for a HMD radar lock. The HMD TD box and TDI line are also in relation to the HMD display, i.e., pilot's head position, rather than to the HUD. The other information on the HMD is interpreted just as though the HMD were the HUD. The HMD is blanked whenever the pilot's LOS approaches the HUD or within the visual bounds of the cockpit so that HMD symbology does not override other display symbology.

At the beginning of each simulation session, the HMD requires boresighting. This is accomplished by depressing and holding the Paddle Switch on the stick. This action causes a Gun Cross to be displayed on the HMD. The pilot then positions the HMD Gun Cross over the HUD Gun Cross, rotates his head so that the HMD and HUD horizon lines are parallel, and releases the Paddle Switch. When the button is released, the HMD disappears until the pilot's LOS leaves the region of the HUD or cockpit, then the HMD reappears, minus the Gun Cross.



- **Helmet-Mounted Display Mode**

Used in conjunction with the HMD; thus, allowing one to lock targets by centering the display on the target by moving one's head.

Figure 11. HMD Weapons Interface

5.0 WEAPON EMPLOYMENT

5.1 Radar Controls and Displays, Conventional Model

Controls for the radar are provided on both the stick and throttle. As far as possible, the radar controls for both the Conventional and Candidate models are identical, but the displays often vary between models. Many of the functions of the radar-related switches on the stick and throttle differ considerably from their functions in the F-16, so these switches have been renamed to be more indicative of their appearance and location, rather than their functions, since function may vary with model. Because of the physical lack of switches in the FITE Lab cockpit, other than those on the stick and throttle, the available controls have been forced to assume additional functions over and above those traditionally performed by Hands-On-Throttle-and-Stick (HOTAS) controls.

Radar antenna elevation is controlled by the thumb wheel on the throttle (as in the F-16). Rotating this thumb wheel forward lowers the antenna elevation and rearward rotation raises elevation. There is a detent at the mid-point of the rotating range. When the thumb wheel is in the detent, antenna elevation is stabilized automatically to remain level in relation to the earth unless a PDT has been designated. With a PDT, as discussed below, radar antenna elevation is automatically centered on the PDT. Essentially, this control functions as in the F-16.

The radar acquisition cursor is controlled by the Slew Button on the throttle, labeled "CURSOR ENABLE" and located just under the speedbrake switch. Control of the radar cursor with the Slew Button is similar to its function in the F-16. Forward pressure on the control moves the cursor toward the top of the radar display, rearward pressure moves the cursor toward the bottom of the display, upward pressure moves the cursor to the left, and downward pressure moves it right. This is where the similarity with the F-16 ends, however.

Target lock (STT) is commanded by placing the cursor over the desired RWS or TWS target, depressing and releasing the Slew Button (F-16 Z-axis actuation).

In the Conventional model, "bumping" the side of the radar display with the cursor controls the azimuth range of the radar antenna search pattern. Selections are +/- 60 deg (the default), +/- 30 deg, and +/- 10 deg. Bumping either side of the radar display when in +/- 60-deg azimuth search reduces the search pattern to +/- 30 deg. Bumping either side of the display again further reduces the scan to +/- 10 deg. Another bump returns the radar to +/- 30-deg azimuth scan, another to +/- 60 deg, etc. When in +/- 30 or +/- 10-deg scan, the center of the search pattern can be slewed left or right by holding pressure on the Z-axis of the Slew Button and "pushing" against the side of the radar azimuth display in the direction of desired movement.

Similarly, bumping the top of the radar display increases the radar range scale one level, while bumping the bottom of the display decreases the range scale.

Additional radar-related controls are located on the sidestick controller. These include the Pinkie Button, Right 4-Way Switch, Castle Switch, and Pointer Button. As the Castle Switch has a radar-related function only in the Candidate model, it will not be discussed in this section. In addition, radar range can also be changed by weapons selection. Selecting MRM automatically places the radar in 40-nm scale, SRM commands 20-NM scale, and selecting GUN places the radar in 10-NM range scale. These scales may be overridden by cursor actuation.

The Pinkie Button is located on the front of the stick near the bottom (F-16 chaff/flare button). This button functions only in the Conventional model to control the radar elevation bar selection. By pushing and releasing the Pinkie Button, elevation bar selection may be cycled through a rotary arrangement from 1-Bar through 2-, 4-, 8-Bar, and back to 1-Bar scan.

The Right 4-Way Switch is located on the left side of the stick about half way up. As the name implies, this switch has four (4) positions in addition to the spring-loaded center position: forward, back, right, and left. Only the function of the rear position varies between models. In the

Appendix J. (continued).

Conventional model, this position selects the RWS mode of the radar, while in the Candidate model the same position selects the HMD mode. Depressing/Releasing the cursor Slew Switch Z-axis breaks a STT and returns the radar to its previous mode. Also actuating the forward position of the Right 4-Way Switch returns the radar to TWS mode from any other radar mode except STT and VSL. In either model, once in TWS mode, forward actuation of the Right 4-Way Switch selects VSL radar mode. Another forward actuation commands BST mode, while the next forward actuation returns the radar to TWS in a rotary fashion.

The left and right positions of the Right 4-Way Switch control SSL mode. Actuation of this switch to the left or right, when in any radar mode except STT, commands SSL mode to that side of the aircraft's nose. Once in SSL, actuation of the switch moves the center of the radar search pattern one notch in the direction of actuation, for example, from left, to center, to right, or vice versa. Attempting to slew the SSL search pattern past its limit in either direction, i.e., actuation of the Right 4-Way Switch to the right when already in the slewed-right condition, returns the radar to TWS mode, just as will forward actuation of the switch. When first entered, SSL automatically maintains the search elevation level with the horizon regardless of the position of the radar elevation Thumb wheel. The search pattern can be commanded to higher or lower elevations with the cursor Slew Button on the throttle. Up pressure on the Slew Button raises the elevation, while down pressure lowers it.

The Pointer Button (F-16 NWS, A/R Disconnect, MSL Step button) is located forward on the right side of the stick. This button is used to designate the PDT in TWS mode in either model. The radar cursor is placed over the desired primary target and the Pointer Button depressed and released to make the selection. A small square appears around the selected PDT. This manual selection of the PDT (Manual PDT) is the only means available in the Conventional model. When a PDT is designated in TWS radar mode with the elevation Thumb Wheel in the detent, radar elevation is centered on the PDT. In addition, when ± 30 - or ± 10 -deg azimuth limits are selected, the antenna centers on the target in azimuth.

In the Conventional model, RWS targets are displayed as small rectangular blocks at the appropriate range and bearing on a conventional monochrome B-scope display. Target history "dots" help in visualizing target movement. Although the Conventional model radar display is typical of many current fighters, no attempt has been made to exactly replicate any specific existing radar display.

The face of the Conventional radar display is scribed by vertical and horizontal lines representing azimuth and range, respectively. The vertical lines denote zero, ± 30 , and ± 60 deg azimuth, while the three (3) horizontal lines divide the selected range scale into quarters. These scale lines are not labeled.

The radar azimuth scan pattern is indicated by the positions of two circles ("balls") along the lower edge of the display. These balls are positioned at the limits of the azimuth search pattern when interpreted relative to the vertical azimuth scribe lines. The radar sweep will be seen to transit the scope from side to side between azimuth limits denoted by the balls. An azimuth caret also indicates instantaneous radar antenna azimuth along the lower edge of the display. As discussed above, azimuth scan selections are commanded by "bumping" the sides of the radar display with the cursor.

As with azimuth, instantaneous antenna elevation is indicated by an elevation caret that moves vertically along the left edge of the radar display. The elevation caret is interpreted relative to small tick marks along this axis, each of which represent 10 deg. The center tick, slightly longer than the rest, represents the nose (longitudinal axis) of the aircraft.

Radar elevation scan pattern is indicated by elevation balls positioned along the left vertical axis of the display. These balls are interpreted relative to the same tick marks used with the elevation caret, but in this case the ticks have a different meaning. The center tick now represents the sea level, and each of the smaller ticks above the center represents 10,000 ft of altitude. The elevation balls indicate the vertical (altitude) coverage of the radar scan pattern at the range of the radar cursor at time. The centroid of the elevation balls moves up or down in response to rotation of the Thumb Wheel.

Appendix J. (continued).

Without a PDT or STT, these balls will be symmetrical about the fighter's current altitude when the Elevation Thumbwheel is in the detent. That is, the antenna will search level with the inertial horizon.

The altitudes of the locked target (in STT) or the PDT (in TWS) are indicated by a small horizontal tick mark just to the right of the altitude scale along the left side of the display. If this tick mark is positioned, for example, midway between the second and third altitude ticks above the center tick, the target is calculated to be at 25,000 ft MSL.

This display also offers an approximation of altitude in RWS or TWS. When the cursor is placed over a target, a short vertical tick mark will appear just to the right of the same altitude scale. The center of this line indicates the estimated altitude of the target under the cursor, while the length of the mark relative to the altitude scale represents the uncertainty in this calculation due to radar beam width.

The separation between the elevation balls, as well as the elevation coverage of the radar search pattern, is determined by the elevation bars selected. The current elevation bar selection is indicated by a digital readout just outside the left edge of the radar display half way between the top and bottom of the display. Choices of 1, 2, 4, and 8 bars are available through actuation of the Pinkie Button on the stick. The vertical limits of the search pattern at the cursor's range are also indicated by a digital readout at the upper left corner of the radar display. The minimum and maximum altitudes, respectively, of the radar's coverage at cursor range are given there in thousands of feet (MSL).

The selected radar range scale (NM) is indicated digitally in the upper right corner of the display. The radar range scale is selected by "bumping" the top or bottom of the display with the cursor. When in STT mode, range is controlled automatically to maintain displayed target position roughly in the upper two-thirds of the radar display.

Along the lower edge of the Conventional radar display is a digital readout of a number of parameters related to Own Aircraft speed and radar cursor geographical position. From left to right, these parameters include ground speed (kts), magnetic bearing of the current cursor position from the selected "bullseye" point, range of the cursor from the bullseye (NM), and true airspeed (KTAS).

Radar target symbols (see Figure 8) may change automatically depending on the action of the automatic TID system in STT or TWS (see Figure 12). If the target is determined to be FRIENDLY, the target symbol becomes a solid circle. A HOSTILE target is indicated by a triangular symbol, while an UNKNOWN target remains a square. Once the type of target has been determined, its identification (i.e., M29, S24, ABUS, etc.) is indicated alphanumerically above the target symbol. STT and TWS target symbols also include a short line representing a velocity vector indicating target course. The length of the velocity vector is fixed in the Conventional model.

When there is a PDT in TWS mode, or a STT, another digital display appears along the top of the radar display containing target-related parameters. From left to right, these include target speed (KTAS), target aspect (TAA), and target magnetic course. TAA is indicated to the nearest 10 degrees. "L- 4" would indicate that TAA is 35-45 deg LEFT of the target's tail, "R-12" indicates 115-125 deg RIGHT TAA, etc.

A STT is commanded by positioning the cursor over the desired target and depressing/releasing the Slew Button Z-axis. STT is indicated when the cursors disappear and the target symbol is enclosed in a circle.

STT is also commanded on the PDT whenever any CIC mode (i.e., VSL, BST, SSL) is selected, regardless of the range. The only difference in selection of STT by the Slew Button or CIC mode selection is the mode to which the radar reverts if the lock is lost. In this event, the radar returns to the last mode selected. So if, for example, the STT is obtained from TWS mode with the Slew Button, the radar returns to that mode when the lock is lost or broken. By contrast, if STT is commanded by selecting VSL with a PDT present in TWS, the radar will return to VSL when the lock is lost or broken. When in STT, the lock can be broken manually and the radar returned to its

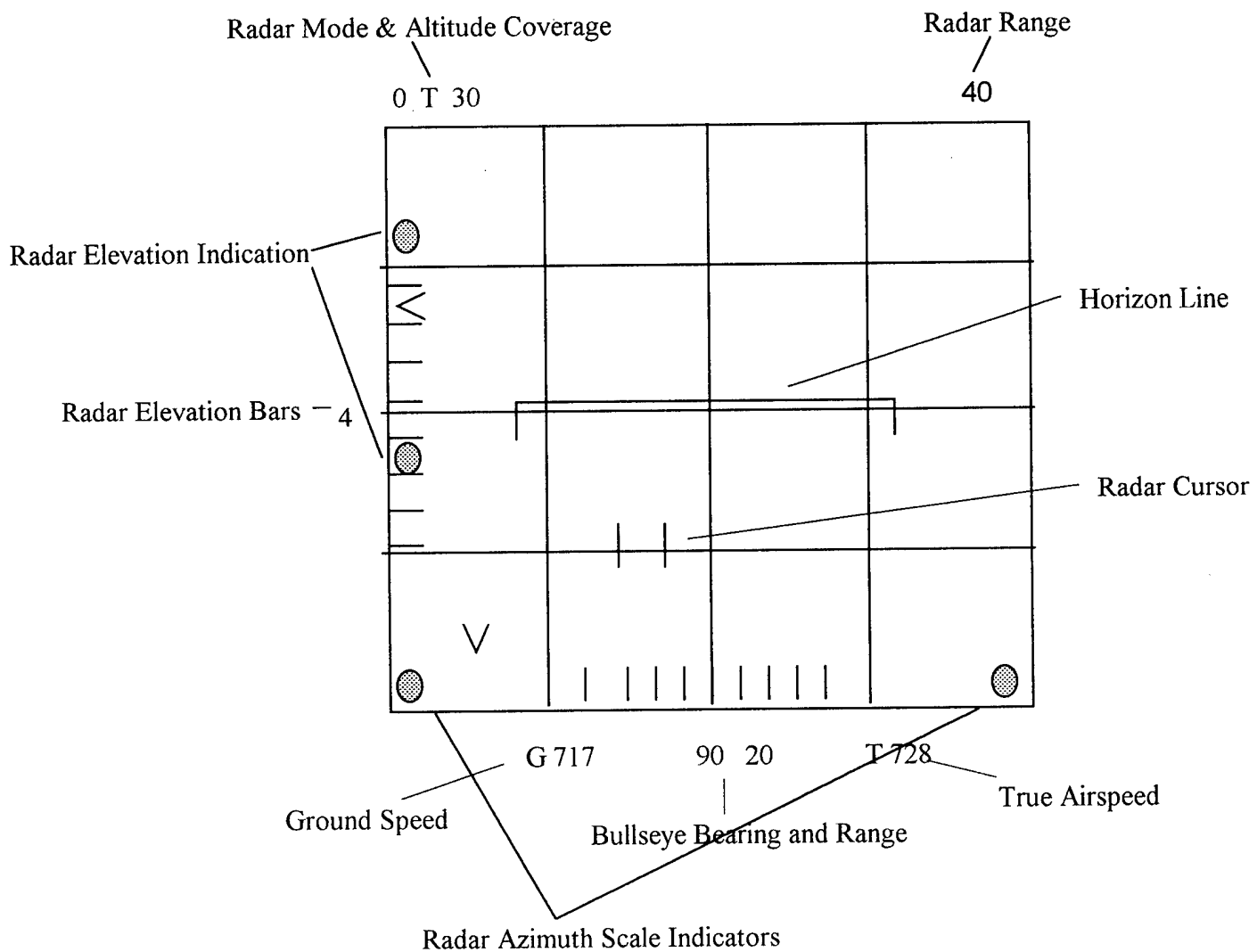


Figure 12. Conventional Cockpit Radar Display

previous mode by depressing/releasing the Slew Button. It should be noted that, with a CIC mode last selected, the target may be relocked automatically if still within the radar's CIC search pattern. Since the STT target is tracked continuously, this mode provides the most accurate and up-to-date information.

Once a STT is achieved, or when a PDT is designated in TWS, an "Aim Dot" will also be displayed. The Aim Dot serves two functions: indicating "collision course" and providing an aiming cue for the MRM. With either GUN or SRM weapons mode selected, the Aim Dot will always indicate collision course. Maneuvering in three dimensions to center the Aim Dot in the radar display at long ranges places the aircraft on collision course with the target, i.e., the shortest path to intercept the target, assuming both aircraft maintain current course and speed. The most effective technique for centering the Aim Dot is to roll the aircraft until the Aim Dot is positioned above the center of the radar screen along its centerline, then pull the Aim Dot toward the center of the display.

With MRM selected in STT, an Allowable Steering Error (ASE) circle is displayed along with the Aim Dot. At ranges well outside the maximum aerodynamic launch range of the MRM, the Aim Dot functions strictly as a collision steering cue as described above. Beginning at 1.1-times maximum kinematic launch range, however, the Aim Dot begins to transition to a pure weapon system firing cue. At ranges inside max launch range, centering the Aim Dot achieves "lead collision" steering. That is, steering is optimized for minimum required MRM maneuvering, or collision steering for the missile, rather than for the fighter. Optimum steering for MRM launch is achieved with the Aim Dot in the center of the radar display. Approximate steering error limits are indicated by the ASE circle, so acceptable steering is indicated whenever the Aim Dot is located inside the ASE circle. At ranges inside the allowable minimum, a large "Break X" is superimposed over the ASE circle.

TWS mode is commanded from RWS or STT modes by actuating the forward position of the Right 4-Way Switch on the stick. TWS mode is indicated in the Conventional radar by a small "T" located between the upper and lower search elevation limits at the upper left of the display. TWS targets change to squares (if from RWS), or the cursor reappears and the antenna resumes its sweep (if from STT). When entered from STT, any target classification or ID already established will remain, and additional targets will be displayed, classified, and identified over time automatically. An Aim Dot and ASE circle (MRM mode only) will also be displayed, based on the PDT.

Weapons envelope information is provided in the Conventional model by a max-range tick mark and a "bracket" along the right vertical axis of the radar display (referenced to the selected radar range scale), a target range caret, and a digital readout of closing velocity. Details of this display are provided below in the SRM and MRM employment discussions.

5.2 Radar Controls and Displays, Candidate Model

The capabilities of the radar are essentially identical between the two models, but the displays are different so there are necessarily some variations in switchology. Every effort has been made to minimize these control variations for training purposes.

Operation and function of the Thumb Wheel in controlling radar antenna elevation are identical between the two models. However, operation of the Slew Button varies somewhat in the Candidate model. For instance, the pushing inward (F-16 Z-axis) with additional pressure while slewing slows the slew rate of the cursor. In this condition in the Candidate model only, whenever the cursor is near a displayed target it "latches" to the target. Continued slewing can move the cursor off the latched target, while releasing pressure on the control commands a lock (STT) on the target.

Since the Candidate radar display is of the Plan Position Indicator (PPI) type, rather than a conventional "B-Scope," the sides of the antenna azimuth search pattern are indicated by black lines diverging outward from the Own Aircraft symbol at the selected angle, rather than the edges of the display itself. Azimuth selections are made by actuating "control buttons" displayed in the lower left portion of the display using the radar cursor. The cursor is positioned over the desired azimuth button and the Z-axis is depressed/released to make the selection. Scan pattern center can be slewed

Appendix J. (continued).

left or right in ± 30 and ± 10 -deg search patterns by positioning the cursor outside the lateral bounds of the displayed pattern on the desired side and depressing the Z-axis of the Slew Button. This causes the search pattern to slew toward the cursor until the Z-axis is released or the edge of the search pattern reaches the position of the cursor.

Similarly, positioning the cursor above the maximum displayed radar range and depressing/releasing the Z-axis increases the selected radar range one level. Z-axis actuation below (behind) the Own Aircraft symbol reduces the selected range one level. As described above for the Conventional model, radar range scale also changes automatically with weapon mode selection.

The Slew Button is also used to command changes in the elevation bars of the search pattern through actuation of "EI Bar Buttons" depicted in the lower right portion of the HDD labelled 1, 2, 4, and 8. To change the selected bar scan, place the cursor over the desired selection and depress/release the Slew Button Z-axis.

There are also some variations in control switchology with the control stick switches. For instance, the Pinkie Button no longer controls radar EI Bars as in the Conventional model, but is used for selecting and deselecting a "declutter" mode of the radar display. Depressing/releasing the Pinkie Button deletes the data (described below) surrounding each target in TWS mode. Data remains only for the PDT, if present. In addition, data still may be viewed temporarily for any target by positioning the cursor over that target. Full data is regained by another activation of the Pinkie Button.

Operation of the Right 4-Way Switch controls radar modes (i.e., TWS, VSL, BST, and SSL) in the same manner as in the Conventional model, except that the rear position of this switch commands HMD mode in the Candidate model, rather than RWS.

The Castle Switch is a 4-position switch located on the stick just below the trim control (Coolie Hat). In the Conventional model, this switch has no radar control function. In the Candidate model, however, the forward and rear positions of the Castle Switch control the radar display format. The default display in this model is a Horizontal Situation Display (HSD) format in which target positions are displayed in azimuth and range as though viewed from above. Actuating the Castle Switch to the forward position selects the Vertical Situation Display (VSD) format, which allows the pilot to view displayed targets as though seen from his own altitude, much like looking out the cockpit. Target azimuth remains the same as in HSD format, but up and down on the display become target elevation angle.

The VSD format is limited to some extent by the discontinuous nature of the current HDD, in which a full-panel display is simulated by individual LCDs. Because of this artifact, the radar scan pattern appears to be discontinuous whenever the aircraft is in a turn. The result is that, although no information is lost, this display may be somewhat distracting. In addition, the apparent angular relationship of the displayed targets relative to the displayed horizon may be accurate only in the center LCD. In other words, targets displayed in other LCDs may appear to be above the horizon when they are actually low, or vice versa. Relative altitude may still be assessed by reference to the orientation of the radar scan pattern relative to the horizon in the center LCD. Also, digital altitude data is still displayed for each target. As in the HSD format, the digital data surrounding each target will be displayed in white numbers when the target is within $\pm 1,000$ ft of Own Aircraft altitude, red when the target is more than 1,000 ft higher, and green when more than 1,000 ft lower. VSD format is particularly useful when attempting to maintain tracking on multiple targets widely split in altitude. A second forward actuation of the Castle Switch returns the radar display to HSD format.

Rearward actuation of the Castle Switch places the radar display into "360" format. With this selection the lowest LCD of the HDD, normally reserved for the SSI, becomes part of the radar display, allowing the pilot to view objects (e.g., waypoints, RWR fans, data-link targets, extrapolated track files, etc.) in his rear quarter. The rear-quarter view presented in this LCD is in HSD format regardless of the format selected for the rest of the radar display. For example, selection of VSD format does not change the HSD format of data-link targets displayed in the fighter's rear quarter. Maximum range displayed in the rear quarter is reduced somewhat from the range selected for

forward-quarter display because the position of the Own Aircraft symbol, located below center of the HDD, does not change. Also, because of the current discontinuous nature of the HDD, some regions in the right and left rear quarters of the aircraft are not displayed. A second rearward actuation of the Castle Switch returns the HDD to the default forward-hemisphere HSD radar display format and restores the SSI.

The Pointer Button on the forward right area of the stick functions as in the Conventional model for manual designation of the PDT in TWS radar mode. In the Candidate model, however, there is also an automatic PDT (Auto PDT) algorithm. With only one UNKNOWN or HOSTILE target displayed, this target is designated as the PDT by default. When any targets are identified as HOSTILE, UNKNOWN targets will no longer be designated by the Auto PDT. With multiple HOSTILE targets displayed, the nearest HOSTILE target is automatically displayed as PDT unless overridden by the pilot with the Pointer Button. Auto PDT designation defaults to the nearest target identified as HOSTILE, even if there is a nearer target identified as FRIENDLY or UNKNOWN. Auto PDT will not designate a target identified as FRIENDLY. As with the Conventional model, in TWS with the radar elevation Thumb Wheel in the detent, radar elevation is centered on the PDT. The antenna also centers on the target in azimuth when $\pm 30^\circ$ or $\pm 10^\circ$ azimuth limits are selected. The PDT is identified, as in the Conventional model, by a small square placed around the designated target.

Auto PDT can be deactivated temporarily by depressing/releasing the Pointer Button when the cursor is not positioned over any target. After Auto PDT has been deactivated, Manual PDT operates as in the Conventional model. Auto PDT is also deactivated temporarily whenever it is manually overridden by a Manual PDT selection. Auto PDT can be reactivated at any time by depressing/releasing the Pointer Button again when the cursor is not positioned over a target.

The primary mode of the Candidate radar is TWS and the default display format is a HSD. Black scribe lines diverge from the nose of the Own Aircraft symbol to denote current radar azimuth limits selected. The total depicted range of the radar is divided into quarters by black arcs centered on the Own Aircraft symbol within the current radar azimuth search segment. These arcs are not labeled.

As with the Conventional model, the Candidate model radar display includes tick marks along the bottom of the center LCD of the HDD which denote each 10° of antenna azimuth. An azimuth caret sweeps left and right along this scale to indicate instantaneous antenna azimuth. Likewise, antenna elevation relative to the aircraft's longitudinal axis is indicated by an elevation caret and scale along the left vertical axis of the center LCD.

The altitude covered by the radar search pattern at cursor range is indicated digitally to the left side of the left cursor line. The lower number denotes the lower limit of altitude coverage, while the upper number is the upper limit in thousands of ft MSL. When the cursors are placed over a TWS target, the target's altitude in relation to the vertical radar coverage is indicated by a short horizontal tick mark across the left cursor line. If this tick mark is positioned midway between the upper and lower ends of the cursor, for instance, the target is in the center of the radar's altitude coverage.

The selected range of the radar (NM) in the Candidate model is indicated digitally in the upper left corner of the HDD. The range scale is increased one step by positioning the cursor beyond the depicted maximum radar range arc and depressing/releasing the Slew Button Z-axis. Range scale is decreased one step by placing the cursor behind the Own Aircraft symbol and depressing/releasing the Z-axis.

Target track files are depicted as solid-colored symbols of various shapes and colors, according to TID system characterization. Square symbols indicate that the class/type of aircraft has not been determined; a long, thin triangle represents a fighter-class target; while a short, wide triangle denotes a bomber-class target. Other classes of targets, such as transports, helos, etc., may be displayed as circular symbols. The color of the symbol confers further information about the identity of the contact. Red denotes a hostile target, yellow is unknown, and green represents friendly targets. Blue targets are members of the fighter's own flight. Once the identity of the target has been determined, its type is displayed alphanumerically (e.g., F15, M29, S24, ABUS, etc.) above the target symbol.

Appendix J. (continued).

When the target's identity is displayed, its shape is also changed to reflect its class (i.e., circle, triangle, etc.)

Data-link targets, those tracked and relayed by platforms other than Own Aircraft, appear identical to those described above except that the target symbols are only hollow outlines, not filled in with color. Data-link targets are not yet implemented in FITE Lab.

The course of the contact can be inferred by the orientation of the target and its associated velocity vector, which points in its direction of movement. In the Candidate model the length of the velocity vector also represents the target's true airspeed, with faster targets having longer velocity vectors. Calculated target Mach number is also displayed digitally just to the left of the target, while altitude, in thousands of feet MSL, is provided to the right of the target symbol. Below the target in HSD format is magnetic bearing and distance in NM (i.e., 030/60) from the selected Bullseye position. As discussed above, the color of the alphanumeric data surrounding each target changes depending on the target's altitude relative to the fighter. In VSD format, the digital readout below the target symbol denotes range in NM. Also, orientation of the target symbol and velocity vector in VSD format represents target course, as in HSD format, not to be confused with climb/dive angle, which is not displayed.

STT is commanded in the Candidate model in the same way as described above for the Conventional model, by placing the cursor over the desired target and depressing/releasing the Slew Button Z-axis. Transition to STT is indicated the disappearance of the radar search range/azimuth segment, loss of the cursor and radar "sweep" line, and loss of any other displayed "own-sensor" TWS targets. (Data-link targets, when implemented, will remain.) "STT" is also displayed in the upper left of the HDD.

Whenever there is a PDT in TWS, or in STT mode, a small red dot is displayed on the HDD. This dot indicates collision course in both heading and attitude when in GUN or SRM weapons mode. Maneuvering the FPM to overlay the collision dot places the aircraft on collision course. As with the Conventional model Aim Dot in MRM mode, the collision dot begins to transition to a lead-collision steering cue for optimizing MRM launch conditions at ranges inside 1.1-times maximum MRM kinematic range. Unlike the Conventional model, however, there is no ASE circle overlaid on the radar display.

In TWS mode, when track files have not been updated for two (2) frames, the target symbol will begin to blink at a 2 Hz rate for another two frames before the track is discarded. During this time, the target position is extrapolated, based on its last-known position and velocity.

Placing the cursor over any TWS target and depressing/releasing the Slew Button Z-axis commands STT on that target. In this mode, as with the Conventional model, only the locked target is displayed. Once implemented, data-link targets will also be displayed in STT mode. As in the Conventional model, displayed radar range is controlled automatically in STT to maintain the displayed target roughly in the upper two-thirds of the radar display. A return to TWS from STT mode is accomplished by depressing/releasing the cursor slew switch Z-axis. Return to TWS is indicated by a resumption of antenna sweep and the black radar range and azimuth scribe lines depicting the radar search pattern. "TWS" is also displayed in the upper left of the HDD.

As with the Conventional model, STT is also commanded on the PDT whenever any CIC mode (i.e., VSL, BST, SSL, HMD) is selected at any range and a PDT is present.

Own-Ship weapons envelope information is presented on the Candidate HDD by envelope "rakes" described below in the discussion of the employment of each AAM. In addition to the usual information on weapon envelope, the Candidate model provides a display of simulated missile flyouts for MRM launches. Own-Ship MRMs in flight are depicted by small blue arrows. The position of the arrow is calculated based on launch and post-launch conditions, assuming the MRM is performing properly. In other words, since there is no communication from the missile after launch, weapon malfunctions will not be detected, so the displayed MRM will continue to follow its prescribed course. The MRM arrow will begin to blink when the missile is calculated to have reached its "active" range, as explained below in greater detail. Once the MRM is calculated to have reached

its closest point of approach to its designated target, the arrow will disappear. When data-link functions are implemented, other friendly MRMs will likewise be depicted in blue.

5.3 Guns

As explained above, the gun and gunsight models implemented by FITE Lab are identical in both the Conventional and Candidate models. GUN mode is selected by the inboard position of the Configuration Switch (F-16 Dogfight Switch) above the Speedbrake Switch on the throttle. GUN mode is verified by reference to any of the visual displays provided. On the Conventional HDD, the bottom LCD contains the SSI (when selected by the rear position of the Castle Switch on the stick). The weapons mode is displayed alphanumerically at the top of the SSI by a letter and a number. GUN mode is denoted by a "G" followed by the number of rounds remaining in ten. That is, a full load (600 rounds) is indicated by "G 60." In the Candidate model the SSI may also be displayed on the lower LCD. In this case, GUN mode is indicated by the gun symbol in the nose of the aircraft outline changing color to blue. The number beside the Gun symbol denotes the number of rounds remaining in tens. On the HUD in both the Conventional and Candidate models, GUN mode is indicated by an alphanumeric "G" and rounds count in the upper left area of the HUD. Likewise, in the Candidate model, the HMD uses the same symbology as the HUD. GUN mode is also obvious on the HUD by presentation of the LCOS gunsight described above. Once gun ammunition is expended, the HUD LCOS display disappears, and in the Candidate model the Gun symbol on the SSI turns yellow.

LCOS symbology is not displayed in the HMD, but selection of GUN mode is indicated by an alphanumeric display similar to that of the HUD.

For the Candidate model, in addition to the direct indications of GUN mode, when the radar is in TWS mode the 10-NM range scale of the radar is automatically selected when GUN mode is commanded.

With a radar lock (STT), the LCOS gunsight computes the LOS to bullets fired at the current time, once they reach target range. With no STT, the reference range (700 or 1,500 ft) is selected by use of the Finger Rotary Knob on the top of the throttle. Although the target may have a TD box associated with it when a TWS track file is established, short-range radar tracking in TWS is not normally sufficiently accurate for gunsight calculations, so a manual LCOS will be displayed until an STT is established.

For tracking gun shots, the recommended procedure is to establish a steady position "in the saddle" relative to the target, attempting to match the target's plane-of-motion by roughly approximating its attitude visually. Generate lead by placing the Gun Cross well in front of the target along its line of flight, then adjust lead by observing the location of the pipper. Although the pipper is somewhat damped for better control, attempting to "fly the pipper" can lead to pilot-induced-oscillations (PIO), prolonging the time necessary for an accurate firing solution. The LCOS POM funnel may provide some help in judging POM but, like the pipper, the POM funnel should not be "flown" to the target. Once in the saddle, if the pipper is out in front of the target, G can be relaxed slowly to "fly the target up to the pipper," increase G slightly to hold the pipper on the target until pipper motion steadies out, then open fire by depressing the Trigger on the front of the stick. Short bursts are recommended due to the limited (about six seconds) firing time available. If, when in the saddle, the pipper is pegged at the bottom of the HUD and flashing, insufficient lead has been generated. Maintain the Gun Cross at its approximate position in front of the target and continue to close on the target until the pipper stops flashing. At this point the solution should be accurate if the pipper is steady, and lead can be adjusted slightly to hold the pipper on the target before firing.

In dynamic situations when a steady tracking gun shot is impractical, snapshot techniques may be used. In these situations the target will appear to be drifting across the HUD. Place the Gun Cross ahead of the target along its line of drift at what is calculated visually to be excessive lead. Check

that the target is within the effective range of the gun (about 2,000 ft) by referencing the analog range bar around the Gun Reticle, the digital range readout in the lower right portion of the HUD, or (without a radar lock) the size of the target in relation to the reticle, then open fire. Continue to fire while holding the Gun Cross in front of the target, as long as sufficient lead is judged to be available.

Under low LOS-rate conditions, when target motion can almost, but not quite, be stopped, the target should appear to be flying up the POM funnel toward the pipper. With a radar lock, the LCOS provides some help in judging sufficient lead in these situations by displaying a "Lead Arc" across the POM Funnel, indicating the additional lead required to offset the current target drift rate. Under semi-steady conditions, with the target well established flying up the POM funnel, fire a short burst as the target crosses the arc. This feature is particularly useful in close-range situations when the aircraft is at slow speed and unable to generate sufficient nose rate to stop the target's LOS drift. Long-range shots, or those under high-G conditions, are normally limited by HUD FOV, so the Lead Arc, like the pipper, is not accurate (indicated by a blinking LCOS). Under these conditions, and in high LOS-rate situations, the Gun Cross is the most reliable firing reference. Maneuver to get the target flying toward the Gun Cross, open fire early, and continue to fire until the target flies through the Gun Cross.

5.4 SRM

The SRM simulated in FITE Lab is a generic all-aspect IR weapon similar to the AIM-9M. SRM is selected by the center position of the Configuration Switch on the throttle. In the Candidate model this action also selects 20-NM range scale of the radar in TWS. Indications of SRM mode on the HDD for the Conventional model include an "S" plus the number of SRMs available (i.e., "S 4") at the top of the SSI. On the Candidate SSI, the number of SRMs loaded is indicated by the number of small missiles depicted on the forward fuselage area of the fighter outline. The particular weapon next in the firing order will be colored blue, the rest green.

In both models, SRM mode is indicated in the HUD by an alphanumeric readout as described above for GUN mode, except in this case the letter "S" is shown, plus the number of SRMs available (i.e., "S 4"). In addition, a small Missile Diamond is depicted, indicating the LOS of the missile seeker. Without a STT or TWS track file the SRM seeker will be caged at boresight in the center of a 65-mil ASE circle. In either model the seeker will slave to the TWS PDT or STT target. In any case, depressing and holding the Finger Rotary Knob on the throttle will, after one second, return the seeker to boresight for as long as the Finger Rotary Knob is held depressed.

When the seeker is pointed at a heat source, whether slaved or boresight, a characteristic "Sidewinder" growl will be heard in the pilot's headset. The seeker may be "uncaged" to track the heat source independently by momentarily depressing/releasing the Finger Rotary Knob. After the seeker has been "forced" to boresight by holding the Finger Rotary Knob depressed for more than a second, uncage is commanded by releasing the Finger Rotary Knob. When uncaged, the seeker diamond doubles in size. If the heat source is sufficiently localized (point source) and intense for successful missile tracking, the headset tone will also change to a high-pitched tone. The SRM seeker will slave to the radar LOS out to about +/- 20 deg, and will track a heat source (uncaged) out to 40 deg from boresight. When outside the HUD LOS, the Missile Diamond will peg at the side of the HUD and blink. The seeker may be returned to the caged/slaved condition by momentarily depressing/releasing the Finger Rotary Knob, or by holding the knob depressed for more than a second (which will also return the seeker to boresight in a caged condition).

In the Conventional model, whenever there is a TWS PDT or STT, a caret appears along the right side of the radar display at the target's current range, with a digital readout to the left of the caret giving closing velocity in knots. In addition, the ranges of significant points of the effective SRM kinematic envelope are indicated along the right edge of the display. A tick mark, appearing at the longest range, is the maximum kinematic range (MAX range) of the SRM, assuming the target continues its current maneuver, speed, and altitude.

Appendix J. (continued).

At a closer range a bracket is located along the right side of the display. The top of this bracket indicates "No-Escape Range." This range is calculated assuming the target performs a level, constant-speed, 7G turn away from the launcher at the instant of firing, continues its turn to the launcher's heading, maintains this heading and speed until the missile reaches close range, then performs a 7G "break" turn toward the missile. The bottom of the bracket indicates minimum kinematic or fuzing range (MIN range) for the SRM under current conditions.

In the Candidate model, SRM effective kinematic envelope is depicted in a similar manner using an envelope "rake." The rake is a blue bracket extending from near the nose of the Own Aircraft symbol on the HDD in the direction of the TWS PDT or tracked target in STT. The far end of the rake indicates maximum kinematic range for the SRM. A smaller bracket at the near end of the rake indicates the No-Escape Range and minimum range of the missile.

The HUDs of both models display a vertical envelope scale on the right side of the HUD just to the left of the altimeter tape. The top of the scale represents 10 NM regardless of the radar range scale when SRM is selected. Information depicted and interpretation of this scale is similar to that described above. In addition, in the Candidate model, the HMD includes an envelope scale similar to that in the HUD.

In the Conventional model, whenever the target is between MAX and MIN ranges, the word "SHOOT" is displayed at the top center of the HUD. In the Candidate model an "IN RANGE" cue is displayed instead in the same location on the HUD and HMD whenever the target is between MAX and MIN ranges. In both models, when the target closes inside MIN range, a large "Break X" is superimposed over the HUD and HMD (Candidate model only).

The SRM, as with all air-to-air weapons in the FITE Lab, is fired by depressing the Trigger on the stick. The weapon may be fired either caged (boresight or slaved), or uncaged, but probability of successful tracking is greater when uncaged and following a target with a high-pitched tone in the headset. The recommended launch procedure is to uncage the SRM with the Finger Rotary Knob when the Missile Diamond is superimposed over the target, a strong audio "growl" is heard in the headset, and the weapons system indicates that the target is within (or approaching) the kinematic range of the weapon. Pause long enough to verify the high-pitched tone characteristic of a good seeker track, then depress and hold the Trigger until the missile leaves the rail. For a caged, boresight launch it is necessary to track the target with the Missile Diamond until the SRM leaves the aircraft. Once launched, the SRM is autonomous and not recallable.

5.5 MRM

The MRM simulated in FITE Lab is a generic inertially-updated, radar guided AAM with an active seeker, similar in concept to the AMRAAM (AIM-120). MRM is selected by the outboard position of the Configuration Switch on the throttle. In the Candidate model this action also selects 40-NM range scale of the radar in TWS. Indications of MRM mode on the HDD for the Conventional model include an "M" plus the number of MRMs available (i.e., "M 4") at the top of the SSI. On the Candidate SSI, the number of MRMs loaded is indicated by the number of large missiles depicted on the rear fuselage area of the fighter outline. The particular weapon next in the firing order will be colored blue, the rest green.

In both models, MRM mode is indicated in the HUD by an alphanumeric readout as described above for SRM mode, except in this case the letter "M" is shown, plus the number of MRMs available (i.e., "M 4"). In addition, a small Missile Diamond with "spiked corners" is depicted at the missile boresight position. Unlike the SRM diamond, the MRM diamond remains at the boresight position at the center of a 131-mil ASE circle and does not slave to the radar LOS.

The MRM ASE circle depicted in the HUD is intended only for relatively short-range "boresight" launches with the missile in the "active" mode, as described below. In this mode the target, should be positioned within the ASE circle at MRM launch to ensure acquisition by the missile.

Appendix J. (continued).

MRM weapon envelopes are displayed in the same manner as described above for the SRM, except that one additional critical range is displayed. This is the range at which the MRM will be launched in the active-radar mode, and it is denoted by a small circle along the right vertical axis of the radar display (Conventional model) or along the envelope rake (Candidate model). Active range is similarly depicted along the weapons envelope bracket in the HUD and the HMD (Candidate model only). Maximum range represented by the HUD/HMD envelope bracket is adjusted automatically based on the displayed maximum range for launching the MRM at the locked target (in STT) or PDT (in TWS). This range scale is adjusted downward one level, regardless of radar range scale selection, as maximum MRM range decreases to less than half the current displayed maximum range.

The "SHOOT" cue displayed by the Conventional model HUD, and the "IN RANGE" cue in the Candidate model HUD and HMD for the MRM are identical to those described above for the SRM.

As with the SRM, the MRM is fired by depressing the Trigger on the stick. Two employment modes are available for the MRM. At long range, the target may be designated to the missile by obtaining a STT or designating the desired target as the PDT in TWS. Maximum kinematic launch range is indicated by the caret along the weapons envelope scale on the radar (Conventional model), the target reaching the top of the envelope rake on the HDD (Candidate model), the carets along the weapons envelope brackets in the HUD or HMD, and by the "SHOOT" message near the top of the HUD (Conventional model) or the "MAX RANGE" message in the HUD and HMD (Candidate model). After launch, guidance updates may be provided to the MRM automatically by the fighter radar while the target is being tracked in STT or TWS, until the missile reaches its predetermined active range. At that point, the MRM activates its own station radar transmitter and searches for the target autonomously. At this point, no further guidance assistance is possible by the fighter radar. Radar guidance updates, although not required for long-range launches, significantly enhance the probability of MRM success, particularly against maneuvering targets.

The MRM may also be launched in "active boresight" mode when within the weapon's active range. For this employment mode, a radar lock is not required. The recommended technique is to maneuver to place the desired target as near the boresight position as possible using the HUD, then depress and hold the Trigger while tracking the target until the missile leaves the aircraft. Once launched in this mode, the MRM is autonomous.

After MRM launch, there will appear a digital Time-to-Go/Active (TTG/TTA) counter just below the weapons envelope bracket on the HUD, radar (Conventional model only), and HMD (Candidate model only). This readout comprises two numbers, side-by-side, where the first number represents the estimated time to impact (secs) and the second number denotes the time until the missile is calculated to transition to the active mode. With multiple MRMs in flight simultaneously, the TTG/TTA readout represents only the last missile launched. When the MRM is calculated to be active, the second number of the readout is replaced by an "A."

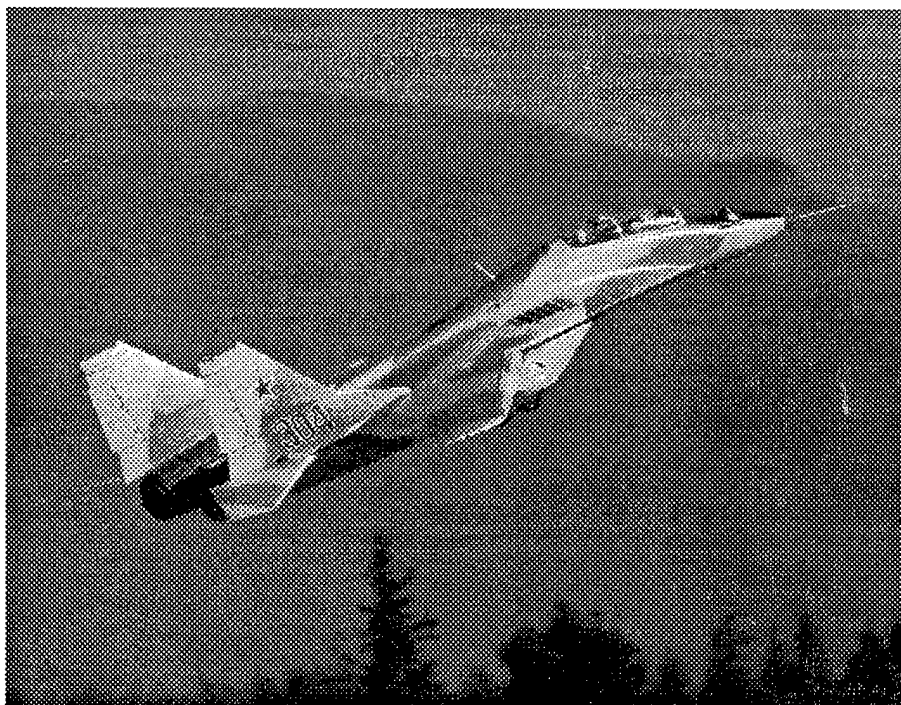
In the Candidate model only, a similar TTG/TTA counter is displayed just to the right of each MRM arrow on the HDD radar display. These numbers are colored blue until the MRM reaches active range, at which time the Time-to-Go counter and the "A" turn red.



F.I.T.E.

Fusion Interfaces for Tactical
Environments Laboratory

1995 THREAT STATION
TRAINING MANUAL



FITE LAB

THREAT STATION TRAINING MANUAL

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LIST OF ACRONYMS

A

AAA	Anti-Aircraft Artillery
AAM	Air to Air Missile
ADI	Attitude Direction Indicator
AGL	Above Ground Level Altitude
AMRAAM	Advanced Medium Range Air to Air Missile
AOA	Angle of Attack
ASE	Allowable Steering Error

B

BST	Boresight Mode
-----	----------------

C

CAP	Combat Air Patrol
CDI	Course Deviation Indicator
CIC	Close In Combat

D

DEG	Degrees
-----	---------

E

F

FITE	Fusion Interfaces for Tactical Environments Laboratory
FOV	Field Of View
FPM	Feet Per Minute

G

GCAS	Ground Collision Avoidance System
------	-----------------------------------

H

HDD	Head Down Display
HMD	Helmet Mounted Display
HOTAS	Hands On Throttle And Stick
HSI	Horizontal Situation Indicator
HUD	Head Up Display

I

Appendix J. (continued).

	IR	Infra Red
J		
K		
	KCAS	Knots Calibrated Air Speed
	KIAS	Knots Indicated Air Speed
	KTAS	Knots True Air Speed
L		
	LCD	Liquid Crystal Display
	LCOS	Lead Computing Optical Sight
	LOS	Line Of Sight
M		
	MRM	Medium Range Missile
	MSL	Mean altitude above Sea Level
N		
	NM	Nautical Mile
O		
	OTW	Out The Window display
P		
	PD	Pulse-Doppler
	PDT	Primary Designated Target
	POM	Plane Of Maneuver
Q		
R		
	RWR	Radar Warning Receiver
	RWS	Range While Search
S		
	SA	Situation Awareness
	SAM	Surface to Air Missile
	SRM	Short Range Missile
	SSI	Systems Status Indicator
	SSL	Sleuable Scan Lock
	STT	Single Target Track

Appendix J. (continued).

T

TAA	Target Aspect Angle
TAS	True Air Speed
TD	Target Designator
TDI	Target Direction Indicator
TID	Target Identification System
TTA	Time To Active
TTG	Time To Go
TWS	Track While Scan

U

V

VSD	Vertical Situation Display
VSL	Vertical Scan Lock

W

X

Y

Z

1.0 THREAT STATIONS

1.1 Controls

The two (2) threat stations currently available to FITE Lab are located in an area adjacent to the primary cockpit. Each station is powered by a single 80486/66Mhz computer and is “flown” by a human operator. Because of greatly reduced computing power when compared with the primary cockpit, the available simulations and functions are also greatly reduced. The flight model currently employed is a greatly simplified F-16 simulation. Threat station controls consist of a stick and a throttle similar to that employed in the primary cockpit, but somewhat different in detail.

The control stick (see Figure 1) used by the threat stations is of the “force” type and very similar to the F-16 stick described above for the primary FITE cockpit. All the switches on the stick are located in approximately the same positions as described above, and operate essentially the same, but may be slightly different in appearance. The Paddle Switch, Pinkie Switch, and Thumb Slider Switch currently have no function for the threat stations. The functions assigned to these controls in the primary cockpit are also not currently available to the threat stations. There is no HMD, no declutter mode for the radar, no selection of radar elevation bars available, and no chaff/flares dispensing in the threat stations.

The Trim Switch (“Coolie Hat”), Pointer Button, Trigger, and Right 4-Way Switch operate in the threat stations in a manner similar to that described above for the Conventional model. As with the primary cockpit, the Pickle Button is not currently functional in the threat stations.

The Castle Switch on the stick controls displays for both the primary cockpit and the threat stations. Since the displays are quite different between these two systems, however, the actions of this switch also differ considerably. Only the rearward actuation of the Castle Switch is functional in the threat stations and is used for selecting/deselecting the Dogfight display. This display is described in greater detail in the following section.

The threat station throttle (see Figure 2) provides for thrust control, including normal and afterburner. Afterburner is selected by reducing throttle slightly below the MIL stop, depressing and holding the AB button located on the front of the throttle, and advancing the throttle through the MIL stop. The throttle may be retarded from the afterburner range to idle without actuation of the AB button. There is no OFF position for the throttle.

The Cursor Slew control on the threat station throttle is located in the same place as in the primary cockpit, but is larger, differently shaped, and functions in a slightly different manner. This control is spring loaded to the center position and can be moved only directly up, down, left, and right. Consequently, radar control is restricted only to vertical and horizontal movement and no diagonal motion is possible. Z-axis control (depressing) is also available and selects/deselects STT for the radar, as with the primary cockpit.

The threat station Speedbrake switch is located immediately forward and above the Cursor Slew Control. Unlike the primary cockpit, this switch is spring loaded to the center position. Holding the Speedbrake switch to the rear momentarily fully opens the speedbrakes, and a momentary forward actuation fully closes them. There is no intermediate speedbrake position. Neither is there any indication of speedbrake operation other than aircraft performance.

The Configuration Switch is located on the threat station throttle just above the Speedbrake switch, as in the primary cockpit. Unlike the corresponding control in the primary cockpit, however, this is a 3-position switch spring loaded to the center position. When in GUN mode, momentary outboard actuation of the Configuration switch selects SRM mode; a second outboard actuation selects MRM mode. Conversely, when in MRM mode a momentary inboard actuation selects SRM and a second inboard actuation selects GUN.

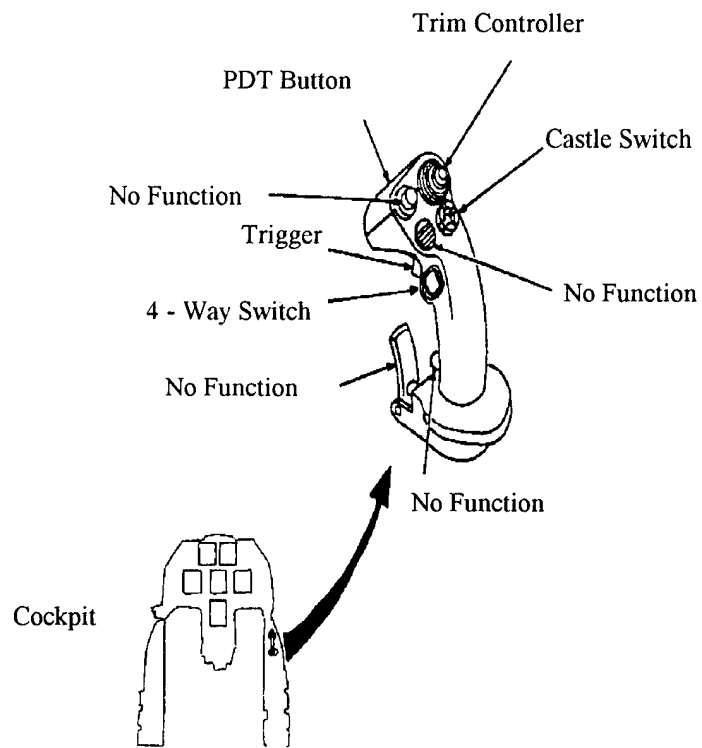


Figure 1. Threat Station Side-Stick

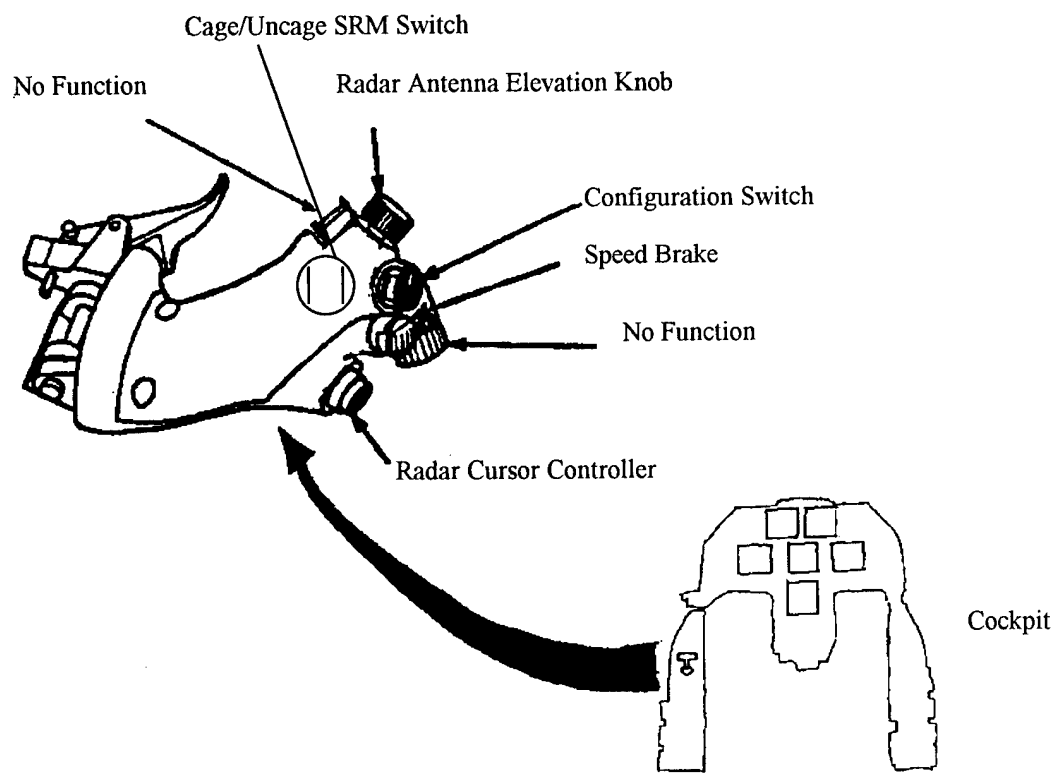


Figure 2. Threat Station Throttle

The threat station radar antenna elevation control is located on the top of the throttle and rotates horizontally. Clockwise rotation of this control raises the radar antenna and counter-clockwise lowers it. There is no detent in this control; the radar antenna currently does not center on a PDT, so TWS targets must be tracked by the operator in elevation.

The radar, weapons, RWR, and TID system capabilities incorporated into the threat stations are essentially identical to those in the primary cockpit. Weapons operations are also basically the same as for the primary cockpit. With the SRM, however, there is no audio tone provided. Nor is there a Finger Rotary Knob on the threat station throttle, so uncaging of the SRM seeker before launch is not provided. Likewise, selection of ranges for the manual employment of the gun is not provided.

1.2 Displays

The threat station displays are all presented on a single 15" color monitor. There are currently three different display formats. The default (Figure 3) is the Radar display, which provides a radar display in the upper left of the screen, a HUD presentation in the upper right, a RWR display in the lower right, and a "God's-Eye" display in the lower left.

The radar and RWR displays are essentially identical to those employed by the Conventional model of the primary cockpit, except that there is no audio associated with RWR for the threat stations. The HUD display is also essentially identical to the Conventional model HUD, except that the waypoint information format in the lower right corner of the HUD is different. This format consists of two numbers, one over the other. The top number is distance (NM) to the selected waypoint and the lower number is magnetic course TO the same waypoint.

The God's-Eye display is designed to offset the lack of an OTW display for the threat stations. This is a small circular display with a vertical and horizontal scribe line. It is interpreted by assuming Own Aircraft is located in the center of the display headed toward the top (as with the Conventional RWR display). The outer limits of the display represent 5 NM range. Any aircraft within 5 NM will be displayed on this scope at its appropriate distance and spatial relationship relative to Own Aircraft. Friendly aircraft are represented by "stick" aircraft and hostile aircraft are represented by small, pointed triangles, all oriented to indicate their course relative to Own Aircraft. There is no indication of altitude on this display.

Due to computational limitations with the threat stations, there is currently no display or indication of weapon MAX or MIN ranges on either the radar or HUD. A range caret and closure rate are provided on the radar with a STT or PDT, as with the Conventional model. Typically, "rules of thumb" are used by the threat operators for weapons envelope estimations. Neither is there an indication of MRM Time-to-Go or Time-to-Active.

The threat station HUD display format is similar to that described above for the Conventional model. The displayed SRM seeker position is represented by a small circle, rather than a diamond as in the primary cockpit.

When GUN mode is selected with the Configuration Switch, the threat station display format is revised as illustrated in Figure 4. The radar display is eliminated and the HUD display is enlarged and placed in the center of the screen. The RWR indicator and God's-Eye displays remain. There is currently no LCOS available in the threat station software; the gunsight reference is a fixed reticle centered on the Gun Cross. Neither is there an analog range bar incorporated with the reticle. Range to targets designated as PDT or with STT is displayed at the lower right corner of the HUD. Any aircraft in the HUD FOV within 3 NM is displayed on the screen. No tracers are provided for the gun on the threat stations.

Another display format, the Dogfight display is shown in Figure 5. The Dogfight display is selected by rearward actuation of the Castle Switch on the stick. The Dogfight display, as its name implies, is intended for close-in maneuvering combat. The center of the screen is dominated by a large outline

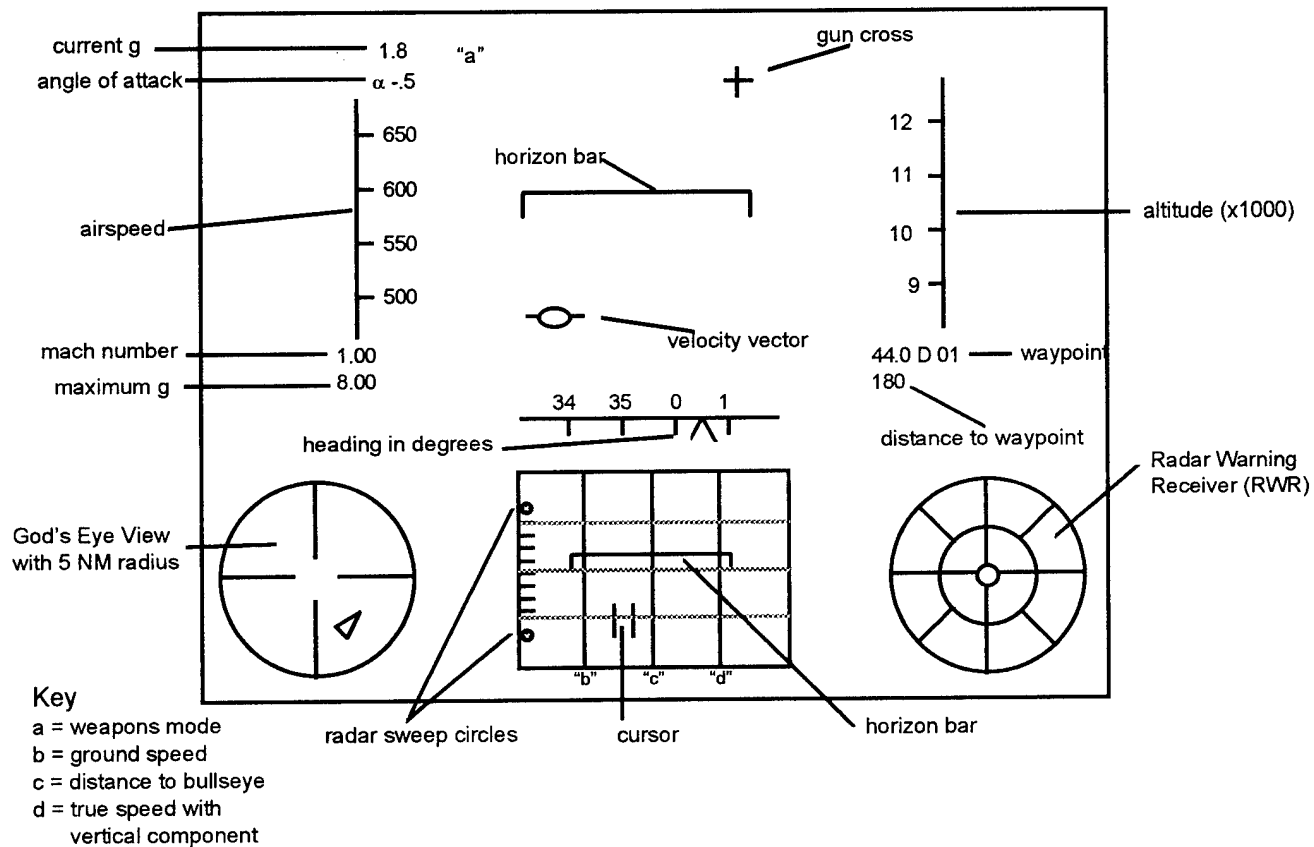


Figure 3. Threat Station Standard Interface.

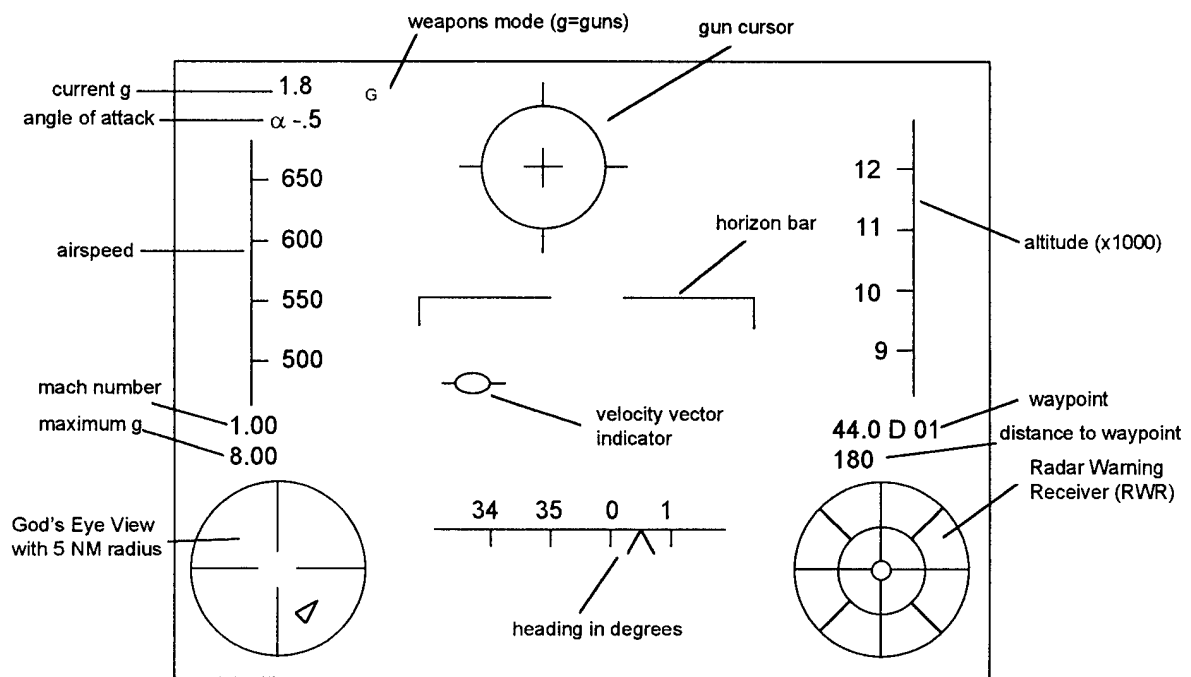


Figure 4. Threat Station Gun Mode Interface

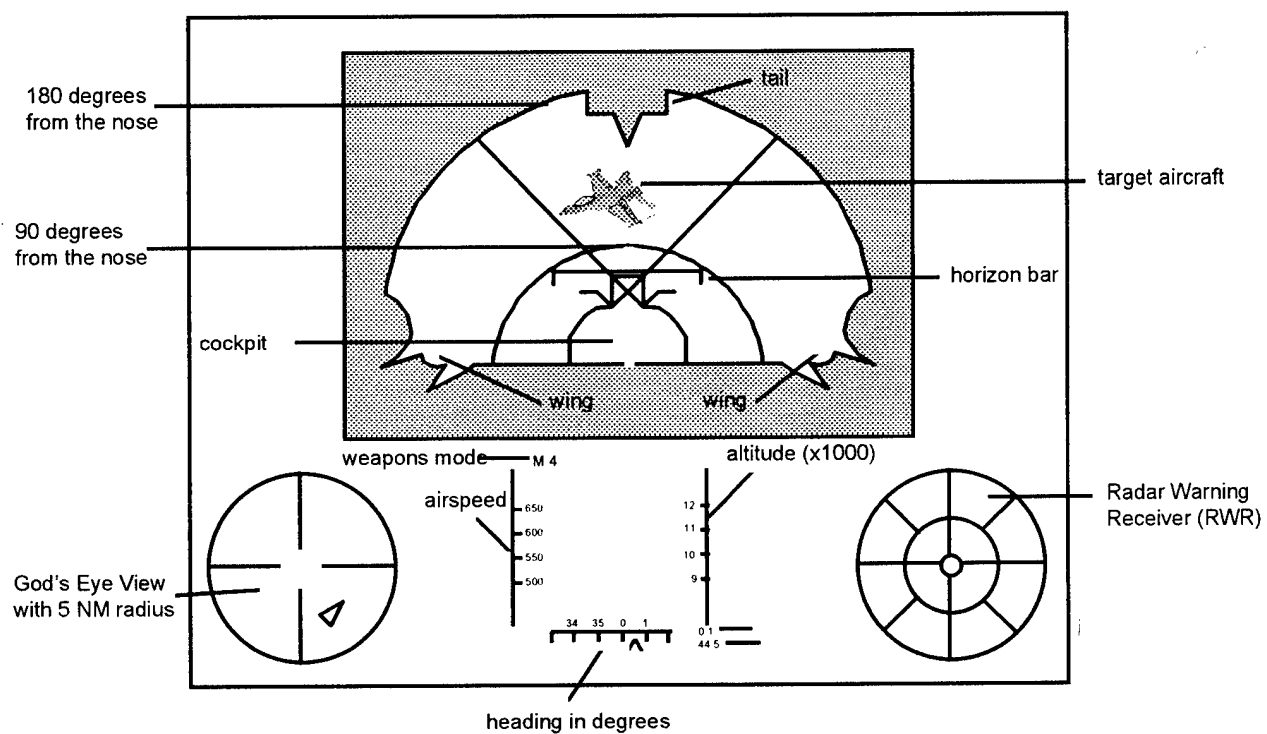


Figure 5. Threat Station Cone Display Interface

that resembles a fighter cockpit canopy, with the outline of a HUD, instrument panel, canopy rails, and aircraft wings drawn along the lower edge. This outline represents the limit of pilot visibility out of the threat station "cockpit." There is no radar display provided, but a miniature HUD is located at the bottom in the center of the screen. The God's-Eye and RWR displays remain unaffected.

In the center of the HUD outline of the largest display is a "waterline" symbol, resembling a "W," typical of the symbol used by many conventional attitude indicators to represent the nose of the aircraft. The center of this waterline symbol represents the nose of Own Aircraft in the Dogfight display. This symbol is surrounded by two concentric semicircles. The inner semicircle represents all points that lie 90 deg off the nose of Own Aircraft. The outer semicircle, also the boundary of the display, represents dead 6 o'clock, 180 deg off the nose of Own Aircraft. As there is a discontinuity here, an aircraft positioned at EXACTLY dead 6 o'clock would be spread evenly all along this outer semicircle. In practice, this seldom occurs and targets remain localized to one spot near the display boundary.

Any target displayed level horizontally with the waterline symbol lies in the plane of the wings of Own Aircraft. Any aircraft that displayed vertically from the waterline symbol lies in the vertical plane of Own Aircraft. At the top of the display, vertically above the waterline symbol, is the outline of the vertical tail of Own Aircraft, as it might appear if the operator could "stand on his head" in the threat cockpit. Aircraft within 3 NM range and within the threat cockpit visual FOV will be depicted on the Dogfight display. A gyroscopic horizon line is also provided on the Dogfight display for operator orientation. Aircraft depicted above this line are higher than Own Aircraft; those displayed lower than the horizon line are lower than Own Aircraft.

With a little practice, the Dogfight display becomes surprisingly intuitive for an operator. Any aircraft located inside the first concentric semicircle is forward of Own Aircraft's 3/9 o'clock line; those aircraft shown outside this semicircle are behind Own Aircraft. A target may be placed on Own Aircraft's vertical axis (lift vector) by rolling toward it until the target is vertically above the HUD outline and its associated waterline symbol. A hard turn under these conditions normally brings a target down the display until it reaches the HUD outline. This is much the same technique that might be employed if the operator visualized the outer semicircle of the display as the "canopy bow" of his fighter. (In reality, of course, aircraft shown near this "canopy bow" are well behind Own Aircraft.)

There is no weapons symbology presented in the Dogfight display. To employ weapons effectively or to monitor radar lock status, etc., the operator must return to one of the other display formats. A forward actuation of the Castle Switch returns the threat station display to the previously selected format.

There is no GCAS available in the threat stations, nor is there any depiction of the ground, so great care must be taken by the threat station operator to avoid "ground collisions."

Appendix K. Summary of Remaining Quantitative Debrief Questionnaire Items

1. NON-SIGNIFICANT QUANTITATIVE RESPONSES BY PHASE

CAP

2. *On a scale from 1 to 10, with 10 being "extremely difficult", how hard did you find the task of maintaining the prescribed CAP airspeed?*

Virtually-Augmented	Conventional
3.71	3.53

3. *On a scale from 1 to 10, with 10 being "extremely difficult", how hard did you find the task of maintaining the prescribed CAP altitude?*

Virtually-Augmented	Conventional
3.76	3.12

4. *On a scale from 1 to 100, what percentage of your available attention do you estimate was allocated to the task of maintaining the prescribed track in the CAP pattern?*

Virtually-Augmented	Conventional
16.29	20.76

5. *On a scale from 1 to 100, what percentage of your available attention do you estimate was allocated to the task of maintaining the prescribed CAP airspeed?*

Virtually-Augmented	Conventional
23.94	27.76

6. *On a scale from 1 to 100, what percentage of your available attention do you estimate was allocated to the task of maintaining the prescribed CAP altitude?*

Virtually-Augmented	Conventional
21.82	23.88

8. *What do you estimate was your greatest deviation from the prescribed CAP airspeed? (in knots).*

Virtually-Augmented	Conventional
57.94	55.29

9. *What do you estimate was your greatest deviation from the prescribed CAP altitude? (in feet)*

Virtually-Augmented	Conventional
1221	1212

Appendix K. Continued

17. *On a scale from 1 to 100, what percentage of your available attention do you estimate was allocated to the task of monitoring and controlling the radar while searching for targets in the CAP pattern?*

Virtually-Augmented	Conventional
---------------------	--------------

35	36
----	----

18. *On a scale from 1 to 100, what percentage of your available attention do you estimate was allocated to the task of visually searching for targets in the CAP pattern?*

Virtually-Augmented	Conventional
---------------------	--------------

21.06	19.5
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Intercept

36. *On a scale from 1 to 10, with 10 being "extremely difficult", how hard did you find the task of maintaining desired airspeed and altitude while performing radar intercepts?*

Virtually-Augmented	Conventional
---------------------	--------------

5.97	5.79
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38. *On a scale from 1 to 100, what percentage of your available attention do you estimate was allocated to the task of visually searching for targets while performing a radar intercept?*

Virtually-Augmented	Conventional
---------------------	--------------

13	14.47
----	-------

39. *On a scale from 1 to 100, what percentage of your available attention do you estimate was allocated to the task of flying the aircraft (i.e., aircraft control, monitoring parameters, navigation, etc.) while performing a radar intercept?*

Virtually-Augmented	Conventional
---------------------	--------------

29.29	23.35
-------	-------

Weapons Employment

42. *On a scale from 1 to 10, with 10 being "extremely difficult", how hard did you find the task of obtaining a radar lock on a target during close-in combat?*

Virtually-Augmented	Conventional
---------------------	--------------

4.68	4.88
------	------

Appendix K. Continued

57. *On a scale from 1 to 100, what percentage of your available attention do you estimate was allocated to the task of monitoring and controlling the radar while performing close-in combat?*

Virtually-Augmented	Conventional
25.29	24.47

59. *On a scale from 1 to 100, what percentage of your available attention do you estimate was allocated to the task of flying the aircraft (i.e., aircraft control, monitoring parameters, navigation, etc.) while performing close-in combat?*

Virtually-Augmented	Conventional
34.41	35

Egress

77. *On a scale from 1 to 10, with 10 being "extremely difficult", how hard did you find the task of determining when egress criteria had been met?*

Virtually-Augmented	Conventional
4.63	5.25

80. *On a scale from 1 to 10, with 10 being "extremely difficult", how hard did you find the task of determining the most direct route to the safe area during egress?*

Virtually-Augmented	Conventional
3.12	3.47

84. *On a scale from 1 to 100, what percentage of your available attention do you estimate was allocated to the task of visually searching for targets while performing an egress?*

Virtually-Augmented	Conventional
15	15.94

87. *On a scale from 1 to 100, what percentage of your available attention do you estimate was allocated to the task of flying the aircraft (i.e., aircraft control, monitoring parameters, navigation, etc.) while performing an egress?*

Virtually-Augmented	Conventional
42.65	44.42

Appendix K. Continued

2. EVENT FREQUENCY ITEMS BY PHASE. (YES/NO Responses).

CAP

14. *Did you make any inaccurate commit decisions? If so, how many?*

Virtually-Augmented	Conventional
6	6

Intercept

33. *Did you ever attempt to intercept or engage a target in error? In other words, did you mistake a friendly for a threat, or a threat fighter for a bomber, etc? Y/N If so, explain.*

Virtually-Augmented	Conventional
4	9

35. *Did you ever spill out of prescribed airspace while performing a radar intercept?*

Virtually-Augmented	Conventional
5	5

40. *Did you experience any instances of loss of spatial awareness while performing a radar intercept? Y/N If so, would you categorize this event as minor, moderate, or severe?*

Virtually-Augmented	Conventional
9	8

41. *Were any G-CAS alerts experienced during a radar intercept? Y/N If so, were you aware of the critical nature of your flight condition at the time? Y/N*

Virtually-Augmented	Conventional
8	3

Weapons Employment

55. *Did you ever "spill out" of prescribed airspace while performing close-in combat?*

Virtually-Augmented	Conventional
2	2

60. *Did you experience any instances of loss of spatial awareness while performing close-in combat? Y/N If so, would you categorize this event as minor, moderate, or serious?*

Virtually-Augmented	Conventional
12	12

Appendix K. Continued

Minor 3	Minor 2
Moderate 6	Moderate 4
Serious 3	Serious 6

61. *Were any G-CAS alerts experienced during close-in combat? Y/N If so, were you aware of the critical nature of your flight condition at the time? Y/N*

Virtually-Augmented	Conventional
---------------------	--------------

13 (7-yes)	7 (0-yes)
------------	-----------

64. *Did you ever lose control of the aircraft during close-in combat? That is, did the aircraft ever do something you did not intend or expect, were you ever below 100 KCAS, did you ever have to recover from a stall or spin, etc.? Y/N If so, explain.*

Virtually-Augmented	Conventional
---------------------	--------------

4	4
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68. *Did you ever UNintentionally fire a weapon outside indicated permissible launch parameters? Y/N If so, explain.*

Virtually-Augmented	Conventional
---------------------	--------------

11	11
----	----

69. *Did you ever Intentionally fire a weapon outside indicated permissible launch parameters? Y/N If so, explain.*

Virtually-Augmented	Conventional
---------------------	--------------

5	5
---	---

75. *Were you shot down? Y/N If so, were you aware of the seriousness of the threat at the time? Y/N If not, explain.*

Virtually-Augmented	Conventional
---------------------	--------------

16/17	14/17
10 yes	10 yes

76. *Were you always aware of the required response to any threat detected? Y/N If not, explain.*

Virtually-Augmented	Conventional
---------------------	--------------

13/16	12/16
-------	-------

Egress

83. *Did you ever spill out of prescribed airspace during an egress? Y/N*

Virtually-Augmented	Conventional
---------------------	--------------

4 yes	5 yes
-------	-------

Appendix K. Continued

85. *Did you experience any instances of loss of spatial awareness while performing an egress? Y/N If so, would you categorize this event as minor, moderate, or serious?*

Virtually-Augmented	Conventional
4/17	4/17
Minor 2	Minor 2
Moderate 2	Moderate 1
Serious 0	Serious 1

86. *Were any G-CAS alerts experienced during an egress? Y/N If so, were you aware of the critical nature of your flight condition at the time? Y/N.*

Virtually-Augmented	Conventional
13/16	12/16

91. *Did you ever hit the ground during a mission? Y/N If so, during what mission phase? If so, were you aware of the critical situation prior to impact? Y/N*

Virtually-Augmented	Conventional
7	9
7 pilots reported Maneuvering Phase	

Appendix L. Summary of Qualitative Debrief Questionnaire Items

A verbatim account of the pilot's responses to the open-ended, qualitative items of the debrief questionnaire are presented. Each question number refers to a corresponding item in the debrief questionnaire, which may be found in Appendix H. Part 1 presents the items in which a specific request for comments was made. These data are summarized in the Results section of the manuscript. In addition, several of the pilots made unsolicited comments in answering various other items on the questionnaire. These comments were retained and are presented as part 2 of this appendix. Each section of this appendix presents the question first in **bold print**, followed by a response from each of the subjects (S' 7-14 USAF; 81-86 French AF; 91-94 RAF). Note that not all pilots responded to every item.

1. QUALITATIVE RESPONSE ITEMS

Question 10) What additional information did you require, or would have been helpful, for maintaining prescribed CAP pattern track, airspeed, or altitude?

S8) Candidate - Better ALT/ AS deviation notification. Conventional - none

S9) Sufficient Alt. moving arrow.

S10) Candidate & Conventional -Voice or visual when deviation exceeded a certain amount.

S11) Some sort of power control instrument and VVI.

S12) If exactness is really required (I know not why) then voice warning would be nice if able to easily disengage.

S81) Conventional - Autopilot - cues in HUD for track. Candidate - same

S82) Conventional - Autopilot total energy marks. Candidate - Autopilot total energy marks

S83) Conventional - Same as Candidate. Candidate - Autopilot

S84) A best altitude background on Candidate

S85) Candidate - Box in HUD. Conventional - Box in HUD.

S92) It would have been helpful if the cockpit could have been turned to stay were it was put!

S93) Candidate - Flight director bug.

S94) Better flight model characteristics both.

Question 11) Do you have any comments on the desirability of the navigation, airspeed, or altitude displays for accomplishing the task of maintaining a prescribed CAP pattern?

S9) Home arrows move on bars.

S10) This was an easy task in both cockpits.

S12) This is Not an instrument holding pattern! Too much attention given that is not necessary.

S84) God's eye view (Candidate) preferable use autopilot.

S86) Accuracy on flying a CAP pattern is not that important.

Appendix L. (continued).

S91) No, it's immaterial as this task is usually done by a an attitude/altitude/speed held/auto pilot type system.

Question 15) What additional information did you require, or would have been helpful, for making the commit decision?

S7) Conventional - larger range bearing read-outs.

S8) Candidate - none Conventional - Better position information.

S9) Candidate - Quicker ID. Conventional - Quicker ID better defined boundaries

S10) Conventional - Did not read miles when I put cursor on closest bomber.

S12) Ground radar.

S81) Conventional - None, only practice.

S83) Conventional - Threat sector display as on Candidate model. Probable inaccuracy in TAA of Conventional B scope model. Candidate - None.

S85) Candidate - Target flash. Conventional - Target flash & design of zone on radar picture.

S86) Both cockpits - ID from further away.

S92) Faster ID - A function of radar processing.

S93) Conventional - Target position/range.

Question 16) Do you have any comments on the desirability of the information and displays provided for making the commit decision?

S7) Candidate - Very easy to determine in threat sector. Conventional - Took more analysis thus time to determine.

S9) Candidate easier than Conventional.

S12) R.O.E. could solve any problems here.

S81) Conventional - The target dots are too small.

S82) Conventional - Better file Candidate - cursor file is not easy to read.

S83) Some commit criteria would be translated into target display types = for example, target meeting commit criteria could be circled, or change shape or color.

S86) Conventional - A moving map giving the bandits position.

S91) Candidate was easier, greater discrimination and use of colour.

S92) Hard to make commit decision on a bunch of contacts on the Conventional scope.

S94) Colour/Vector/ reduction better in Candidate cockpit.

Appendix L. (continued).

Question 20) What additional information did you require, or would have been helpful, for determining and controlling search volume in the CAP pattern?

- S7) For both, some indication, visual or aural, that you have changed a setting.
- S10) Candidate - Vertical (elevation) graphically displayed. Conventional-Graphics of angles (horizontal & vertical).
- S12) Declutter switch to read #'s.
- S81) Candidate - Putting at the same place. Bars selection, angles of sweep selection and altitudes selection.
- S82) Conventional - Elevation and range display. Candidate- Elevation/range display; touch screen for azimuth and bar selection.
- S85) Information of altitude. A vertical 2 dimension view fighter and altitude. Angle = number of radar bars-targets, distance with cursor where the beam hit the ground.
- S86) A sketch of the area superimposed on the radar scope.
- S92) Information was fine.
- S94) Candidate - allocated information (see angle/ el/bars).

Question 21) Do you have any comments on the desirability of the information, displays, or controls provided for determining and controlling radar search volume in the CAP pattern?

- S7) Candidate - Use a throttle or stick switch to change bars like conventional cockpit.
- S10) Candidate - No graphics of elevation of radar.
- S81) Conventional - The control for the volume selection (altitude) is not ergonomic.
Candidate - Scattered information or selections.
- S83) Two Dimensional display x and Z axis.
- S86) You are interested in reading the radar looking for a certain azimuth. I really like how you select bar numbers. Why not have the radar select bars automatically for the required scan.
- S92) It would have been better to be able to control scan width and bar scan with buttons on cursor position.
- S93) Candidate - Easier means of changing range scale. Conventional -Easier means of adjusting scan angle.
- S94) Candidate - different cursor colour/shape required to differentiate from background.

Question 28) What additional information did you require, or would have been helpful, for performing radar intercepts?

- S12) GCI to ID "leakers".

Appendix L. (continued).

S14) Attitude indicator on the Candidate. Several times while doing a tight 360 deg. turn I found myself in an unusual attitude if I focused on the display and not on the HUD.

S82) Conventional & Candidate - Weapons envelope target no escape zone raid mode zoom.

S83) Automatic targeting on most dangerous aircraft.

S85) A expanded view mode of the targets to choose or know what target was chosen in the package.

S86) Candidate - Vertical display. Conventional - Range x altitude.

S92) It would have been much better to have had one screen rather than 6 in the Can model. I was often distracted by breaks in the screens

S93) Candidate - A means of electronically zooming on the "pack".

S94) Candidate -better display without gaps. Conventional - bigger display.

Question 29) Do you have any comments on the desirability of the information, displays, or controls provided for performing radar intercepts?

S9) Candidate CRT set-ups (spaces between screen) inhibited intercept & sort relative to Conventional.

S10) The bar between the top 2 displays was very distracting.

S81) Candidate - The cursor is not easy to use in terms of brightness and movements. It could limited.

S83) Need of a RAM (raid assessment mode) for better sorting targeting (or a "zoom").

S84) It would be interesting to plan PDT's and out of the range and begin to fire when the first is in range.

S86) Candidate - Cursor displacement laws inadequate; range scales tedious to change. Conventional - Radar azimuth easily changed when working close to the edges and mistake difficult to notice.

S91) Candidate: Awesome! Conventional: For collision perhaps addition of "own projected flight path with a turn symbol to simplify a roll-out in stern conversion.

S93) Cursor slow rate could be improved in both cockpits - it is too sensitive.

S94) Candidate - No gaps more coherent displays more visible cursor different range scale change mechanism. Conventional - Bigger screens.

Question 31) What additional information did you require, or would have been helpful, for identifying friendly/hostile targets?

S9) Friendly IFF button.

S12) Candidate - Faster IFF. Conventional - Faster IFF.

S86) A slightly quicker ID would have been helpful.

S91) AWACS

S92) Bigger scope or colour on Conventional model.

Appendix L. (continued).

S93) Candidate - Declutter more quickly.

Question 32) Do you have any comments on the desirability of the information, displays, or controls provided for identifying friendly/hostile targets?

S7) Candidate - The split screen made it difficult to keep track of targets at longer ranges.

S9) Red & green are nice no #'s assuming no weird lighting conditions.

S11) What would have been nice is if the system could have identified the target as friendly or hostile more quickly.

S12) Add feature to speed up IFF with cursor over target.

S81) Conventional - The display is too small to have a good visibility's against so many targets.

S85) On the Candidate picture the name of the aircraft should be written for best SA without interpretation

S91) Candidate much easier/ nicer because of colour & discrimination advantages.

Question 43) What additional information did you require, or would have been helpful, for obtaining radar locks during close-in combat?

S10) Better visual to make better use of the helmet.

S12) Candidate - Better visuals. Conventional - Better visuals.

S84) A more accurate HMD.

S85) A larger boresight scan.

S86) Auto acq modes should have a higher priority than the other.

S91) More practice at this (e.g. using Drone F-15 for target practice during training sessions).

S93) Left/right scan horizon stabilized, could be presented visually on HUD.

Question 44) Do you have any comments on the desirability of the information, displays, or controls provided for Close-In Combat (CIC) modes of the radar?

S7) I found them both relatively easy to use and understand.

S10) I would have required several more hours for training to be able to do CIC more proficiently for this non-fighter pilot.

S12) Candidate -Declutter more!

S82) Conventional - SRM not slewable when lock on not equal target than radar. Candidate- HMD symbology too much clutter.

S83) HUD display of SSL must remain parallel to horizon.

Appendix L. (continued).

S84) To much information in HMD.

S85) A more ergonomic control to select CIC.

S92) When an STT is broken - the radar should default to no CIC mode rather than that previously selected.

Question 45) Which CIC did you prefer during close-in combat?

Boresight (BST)

Vertical Scan Lock (VSL)

Sleuable Scan Lock (SSL)

Helmet Mounted Display (HMD) (when available)

Why?

S7) Candidate - Boresight. Conventional- Boresight. For me, it was the easiest way to lock-up target.

S8) Candidate - HMD Conventional - BST

S9) Candidate - HMD look-lock SSL- clear in direction of turn.

S10) Didn't have to look down.

S11) VSL it was easy to place the target along the vertical line and then pull the aircraft to the target.

S12) Candidate - VSL. Conventional - VSL Because I did not have adequate visuals.

S14) Easy to see the VSL superimposed over the target.

S81) Conventional - BST and VSL I'm used to. They are designed for dogfight.

Candidate - Same HMD was not useful for 2 main reasons.

-Symbology not adapted.

-Priority to HUD symbology not so easy to use. HMD transmissivity very bad.

S82) Conventional - BSL/BST VSL adapted to close in combat velocity vectors in same plane.

Candidate - Does not read to change flight path hardly.

S84) HMD is best on a accurate target. SSL would be interesting if links to the aircraft and not to the ground reference.

S83) Probably because of simulation limits = easier to lock on a narrow target seen in the HUD. HMD was almost not used in CIC. BST locks faster than any other CIC.

S85) VSL- because BST is so small. SSL the CIC control is difficult to push right or left. HMD was not reliable.

S86) BST quicker lock, or SSL to lock on target you don't see.

S91) Because of greater flexibility and ease of compared with others

S92) BST: Fastest lock time. Should come up before VSL.

S93) More vertical scan towards lift vector.

Appendix L. (continued).

S94) Easiest to use, but all modes utilized at various stages.

Question 52) What additional information did you require, or would have been helpful, for performing close-in combat?

S9) Rear vision.

S10) Don't know.

S11) Knowing what the other pilots were thinking.

S12) GC

SI7) Candidate - none Conventional - TCAS!

S81) Conventional - Accurate attitude information GCAS information fuel information.
Candidate - Do not display ADI only tactical symbology.

S82) Conventional - Not equal scale on ECM display. Candidate - Threat symbol in HUD.

S85) A much more clever HMD with arrows showing the direction of the threat.

S86) A radar that could track the other targets in the same time.

S91) Better gunsight.

S94) Better visual displays flight model characteristics

Question 53) Do you have any comments on the desirability of the information, displays, or controls provided for performing close-in combat?

S7) I stayed on the HUD pretty much during check. The displays were only scanned for a second. I have no real comments here.

12) Super close-in search mode for the radar.

S81) Candidate - ADI on request only.

S84) Simplify HMD.

S85) A clever HMD.

S92) See earlier comments

S94) Missile approach warning for Sidewinder type missiles

Question 62) What additional information did you require, or would have been helpful, for avoiding or recovering from critical low-altitude situations?

S7) None, the warnings were excellent.

S9) Candidate - good GCAS. Conventional - too bright.

S10) Good GCAS system.

Appendix L. (continued).

S12) Voice warning.

S81) Conventional - A good scale of attitude in the HUD.

Candidate - A reel scale of altitude is the HUD.

In HDD no overlap between horizontal and vertical information. ADI available upon pilots request.

S82) Conventional & Candidate - Better visualization of outside window display

S84) A better attitude feedback.

S85) GCAS very good.

S93) Voice readout of speed when it changes by > 50 kts (referenced from 412 kts).

Question 63) Do you have any comments on the desirability of the information or displays provided for avoiding or recovering from critical low-altitude situations?

S7) Candidate - No. Conventional - Need a warning here.

S9) Candidate - excellent A/S alert would be nice. Conventional - What GCAS horizon was okay (better visual all need & alert on A/S).

S11) The system in the Candidate cockpit was wonderful. The system in the Conventional cockpit was not as effective.

S14) The GCAS is very helpful.

S84) Linked to that GCAS was good

S91) Very nice.

S92) GCAS was good.

Question 66) What additional information did you require or would have been helpful, for determining permissible and optimum weapons launch parameters?

S7) Candidate - None Conventional - None For both what was there was fine. I just needed to look at it (fired out of range a few times).

S8) Change symbology not just add "shoot" or "in range."

S9) Shoot cue - not in range words.

S11) Some sort of analog display showing the weapons parameters would have been helpful. Something that would show how far in or out of the parameter's the aircraft was.

S12) No escape parameters.

S82) Conventional & Candidate -Bigger in range/shoot.

S83) Analogic display for close-in need in Gun mode.

S84) A range where the aircraft can fire its weapons without having to aim on the targets.

Appendix L. (continued).

S86) A better readable range scale.

S93) Voice calls of shoot/in range.

S94) Rate of approach to max/min limits (both).

Question 67) Do you have any comments on the desirability of the weapons envelope displays for accomplishing the weapons employment task?

S7) Displays were good. Put a interlock in there so you can't fire unless in range.

S9) Fly out dot or time of flight center bigger "A" or farther from scale.

S10) Candidate - Good HUD display.

S83) Envelope display looked confusing in Candidate and Conventional cockpit it radar displays, and not very accurate and readable in HUD.

S82) Candidate - Lack of drawing envelope target (HDD).

S84) See previous RMR.

Question 71) What additional information did you require, or would have been helpful, for determining the location, status, and threat of hostile aircraft?

S7) Candidate - No split screen.

S9) Longer range radar, both.

S10) Maybe a change in symbology when a threat has you within his weapons range.

S12) You can never have enough information.

S86) Conventional - more appropriate scale.

S91) Method of "magnifying" the limited area where the threat was displayed on the Conventional cockpit without altering the radar set-up. (i.e. make it more like the Candidate in the area of interest).

S92) Quicker radar pickups!

S94) Candidate - no gaps in display more visible cursor. Conventional - bigger display.

Question 72) Do you have any comments on the desirability of the defensive systems displays (i.e., RWR and hostile weapons envelope boundaries) for determining the location, status, and threat of hostile aircraft?

S7) Candidate - I liked the displays for this cockpit Conventional - Add a missile inbound warning light of some sort

S9) Candidate - good/how realistic. Conventional - good.

S11) The display in the candidate cockpit was much nicer.

Appendix L. (continued).

S12) The RWR needs to be mechanized to expand the area that is the greatest threat.

S83) Hostile weapons envelope boundaries desirable.

S84) An idea of the elevation is missing (Attitude at a fixed range of 20 NM).

S85) Three -D sound is very good, red beams on radar picture as well.

S86) Hostile weapons envelope boundaries would be helpful.

S92) RWR display in Candidate was much clearer an easier to intercept.

S94) Colour simulation display with radar.

Question 73) What additional information did you require or would have been helpful, for determining the status of defensive expendable systems?

S8) Audible indication of expendable deployment or empty condition don't have time to look for "chaff" or "flare" to see if it went.

S9) Fine as was.

S10) Forgot to use defensive expendable.

S12) Voice warning of # remaining of chaff or flares.

S86) Candidate - Counters in the HUD.

S91) A head-up warning of; say 10% remaining, e.g. chaff is on dispense when this is reached, instead of "chaff" on dispense; or perhaps only put the caption head up when it gets to a low amount left (i.e. only go to head as warning of little left instead of dispense confirmation).

S93) Chaff/flares displays on L/R LCD's all the time as an "inset".

S94) Voice warning of missile availability.

Question 74) Do you have any comments on the desirability of the controls and displays for the expendable system?

S9) Fine -generally chaff & flares are on throttle quadrant not stick.

S81) Conventional - Controls not ergonomic. Candidate - Controls not ergonomic.

S85) To change radar picture scale is a lot too difficult - direct voice input.

S86) Counters in the HUD

S94) Should be permanently available.

Question 78) What additional information did you require, or would have been helpful, for determining egress criteria?

S7) For both, larger DME readout.

Appendix L. (continued).

S8) Whether target aircraft had been destroyed.

S9) Remaining bogies - friendly or for IFF faster.

S10) Look behind radar.

S12) Voice warning.

S81) Candidate: Joker fuel information

S83) Information on results of missile shots!

S84) A backtrack radar.

S86) A god's eye looking at your 6 o'clock.

Question 79) Do you have any comments on the desirability of the displays provided for determining egress criteria (i.e., fuel, weapons, expendable displays, etc.)

S10) There's no fuel display unless you use one of the situational displays.

S81) Display the ???

S82) Fuel sound.

S94) Should be visible below preset levels.

Question 88) What additional information did you require, or would have been helpful, for maintaining performing an egress?

S7) Larger DME readout.

S8) Candidate - "Home pointer."

S11) Most direct route/course/heading to home plate on the Candidate model.

S12) GCI

S85) Candidate - An index or a box in HUD to show the base. Conventional: Tactical situation with airspace's etc. around aircraft.

S94) Clearer display of prescribed airspeed

Question 89) Do you have any comments on the desirability of the navigation, airspeed, or altitude displays for performing any egress?

S8) Hard to maintain ALT.

S91) Candidate easier moving map would make the Conventional better but both are, frankly, absurdly easy as the destination selected (home plate waypoint) is always telling you where to go!

S92) Much easier on the Candidate. A moving map would have been an advantage in both aircraft.

Appendix L. (continued).

Question 90) Do you have any additional comments about anything not covered elsewhere in the questionnaire, including the simulations, facilities, scenarios, procedures, etc.?

S10) Candidate - The disconnects between displays was distracting/frustrating/ debilitating sometimes. Several times I lost the cursor- maybe have a way of putting the cursor to a "home" point.

S83) - Threat terminals should not crash (it allows the cockpit to be less threatened, regardless of the ability of its pilot to achieve the task, but, only because of a mistake of a threat terminal pilot, who is not suppose to be evaluated!).

Friendly F's should not be so easy to be identified by threat terminals; it should be kept closer to the cockpit, so that it becomes a wingman, and is seen as so by the threat terminals.

Serious locked always similar, but, results depended in large part on the reactions of the cockpit pilots with the interface, especially in Candidate model, and due to the gaps between the 3 upper central success (cursor management).

S84) In the Candidate the streaming of the ground in the HDD wasn't convenient- too fast .

S85) Attitude information on candidate were not good at all. GCAS arrow was wonderful. HMD was very poor for combat and all information like speed, alt, heading were rather too much place. Three-D sound was wonderful during close in combat.

S86) Did you take into account the poor readability or the HUD and the poor quality of the outside world.

S94) To obtain best value rebrief parameters/requirements before each flight (briefly) and prior to final debrief. * for each phase (only needs to be paraphrased).

2. ADDITIONAL COMMENTS

Question 14) Did you make any inaccurate commit decisions? Y/N If yes, how many?

S83) Conventional - No. Candidate -Yes, no commit or fighters (not seen) 1 or 2.

S92) Yes, 2, Committed to friendly twice - both times in Candidate.

Question 18) On a scale of 1-100, what percentage of your available attention do you estimate was allocated to the task of visually searching for targets in the CAP pattern?

S12) Visually using the radar.

Question 19) On a scale from 1-10, with 10 being "extremely difficult," how hard did you find the task of determining and controlling radar search volume while in the CAP pattern?

S93) Conventional - Having to go to top/bottom of screen and press cursor was awkward.

Question 22) On a scale from 1-10, with 10 being "extremely difficult", how hard did you find the task of performing a radar intercept to a desired point?

S12) Target with No threat of missiles.

S92) 8 For both, because I was always being threatened before being able to conduct an academic intercept.

Appendix L. (continued).

Question 23) On a scale from 1-10, with 10 being “extremely difficult,” how hard did you find the task of determining your position relative to a target during an intercept?

S81) Conventional - 8 for value, but 2 in the scope. Candidate - same.

S83) Candidate - Five, no accurate idea of range, depending on scale, too.

Question 25) On a scale from 1-10, with 10 being “extremely difficult”, how hard did you find the task of determining the capability of your weapon system during an intercept?

S12) R.O.E. dependent.

S92) Candidate - 4 Conventional- 4 It would have been better to have had dynamic weapons range algorithms rather than a fixed “in range” work at 25 NM for MRM.

Question 26) On a scale from 1-10, with 10 being “extremely difficult,” how hard did you find the task of determining your relative tactical advantage versus the target during an intercept?

S92) Mostly this refers to the times I was threatened by the target.

Question 30) On a scale from 1-10, with 10 being “extremely difficult,” how hard did you find the task of identifying friendly/ hostile targets?

S83) Conventional - Four because of too small radar display difficult between circle and triangle
Candidate - Two (color difference and large display).

Question 33) Did you ever attempt to intercept or engage a target in error? In other words, did you mistake a friendly for a threat, or a threat fighter for a bomber, etc.? Y/N If, so, explain.

S9) Yes- in Conventional during dogfight with apparently 2 enemies - drawn into extension by friendly.
Could have happened in either cockpit.

S10) Conventional -Yes, shot down my friendly F-15.

S11) Yes, once I thought the friendly was an enemy fighter.

S12)Yes, but only because not enough training prior to runs.

S14) Yes, only when I tried a missile before the ID came on the screen.

S81) Conventional - Yes, friendly fighter before ID. Candidate - Same.

S82) Yes, one fired within hostile package.

S83) No, but it could have happened easily (because of #30).

S86) Yes, the ID is a bit slow. 12B-34) I really did not know that this was a requirement.

S91) End of an engagement, thought I heard a gun attack from behind and became involved in lengthy visual “heads out” flight with an F15 using guns.

S92) No, Committed off on the F15 on 2 occasions but, realized mistake.

Appendix L. (continued).

S93) Yes, fired before identifier due to a high threat from two directions - one turned out to be friendly.

S94) Candidate - Yes, three previous sessions on Aux - shot F15.

Question 34) On a scale from 1-10, with 10 being "extremely difficult," how hard did you find the task of remaining within prescribed airspace while performing radar intercepts?

S92) Nine or ten for both, because I was often threatened and had to evade.

Question 35) Did you ever "spill out" of prescribed airspace while performing a radar intercept?

S7) Candidate - No, did after engaging a fighter.

S83) Conventional - Probably not, but not checked at all. Candidate - one

S86) Candidate - Almost (target on the border). Conventional - Maybe.

Question 36) On a scale of 1-10, with 10 being "extremely difficult," how hard did you find the task of maintaining desired airspeed and altitude while performing radar intercepts?

S12) Airspeed was not a #1 priority as radar locks and they took time after missile launch it was time to defeat inbound missiles.

S81) Conventional - Four to 5 an auto pilot would have useful. Candidate - Same.

S83) Three, but not a lot of attention dispensed to those parameters, especially airspeed.

S91) Candidate - 10- because I did not consider it in this least bit important.

S92) I didn't really complete an ??? intercept so this does not apply.

Question 37) On a scale of 1-100, what percentage of your available attention do you estimate was allocated to the task of visually searching for targets while performing a radar intercept?

S12) Candidate - A little easier for me.

Question 38) On a scale of 1-100, what percentage of your available attention do you estimate was allocated to the task of visually searching for targets while performing a radar intercept?

S83) Visually in the radar 20% Outside 0%.

S86) Conventional - Visual is poor does not encourage to look outside

Question 39) On a scale of 1-100, what percentage of your available attention do you estimate was allocated to the task of flying the aircraft (i.e. aircraft control, monitoring parameters, navigation, etc.) while performing a radar intercept?

S81) Candidate - During first experiments misunderstanding between speed vector and markup in the HDD.

S93) Both 98% (remaining 2% was due to overload & thus not flying aircraft). Flying aircraft is in parallel with other task. e.g. radar.

Appendix L. (continued).

**Question 40) Did you experience any instances of loss of spatial awareness while performing a radar intercept? Y/N If so, would you categorize this event as minor, moderate or serious?
Min/Mod/Ser**

S14) Yes, moderate in the Candidate cockpit, but only when doing a tight 360 deg. and I took my eyes off the HUD.

S83) Minor during intercepts. Considered as simulation limitation in outside orientations and feelings.

S92) Yes, for both ended up unusual attitude occasional moderate to serious.

S93) Yes, I experienced all three severity's in both cockpits.

Question 41) Were any GCAS alerts experienced during a radar intercept? Y/N If so, were you aware of the critical nature of your flight condition at the time? Y/N

S7) Candidate - No, did during engagements.

S12) GCAS were experienced during missile defense.

S91) Not during intercept, as I recall. However, definitely during evasion. This would have been less critical in the real world by day over bumpy terrain, but entirely serious at night or over featureless terrain by day.

S93) Candidate- Only. Yes, sometimes aware but, on at least 3 occasions the GCAS prevented ground impact.

Question 42) On a scale of 1-10, with 10 being "extremely difficult" how hard did you find the task of obtaining a radar lock on a target during close-in combat? If no close-in combat, mark NONE.

S85) Candidate - Three, and 8 with the HMD. Conventional - Three

S91) 6 - Not experienced much, but with practice on the shorter radar modes and HIM. I believe this would have become a lower figure.

S92) On fast targets 2-3 on subsequent targets (bombers close together). Six or seven it would come up in same CIC mode on lock break - often re-locked to same target.

Question 46) On a scale from 1-10, with 10 being "extremely difficult," how hard did you find the task of performing close-in combat in this controls/displays version?

S92) Seven -Handling the "aircraft" was hard and monochrome background made for poor spatial orientation.

Question 47) On a scale from 1-10, with 10 being "extremely difficult," how hard did you find the task of determining your position relative to your primarily opponents during close-in combat?

S12) It depends if you're just coming out of missile defense or not.

Appendix L. (continued).

Question 48) On a scale from 1-10, with 10 being "extremely difficult," how hard did you find the task of determining your threat from an opponent's weapon system during close-in combat?

S12) You really don't know what weapons is being shot at you.

S83) Nine, sounds were too low.

S92) Not applicable.

Question 49) On a scale from 1-10, with 10 being "extremely difficult," how hard did you find the task of determining the capability of your weapon system during close-in combat?

S12) With midrange missiles available and required to use, their capability was always a big question in mind.

S92) Seven - No dynamic weapons ranges.

Question 50) On a scale from 1-10, with 10 being "extremely difficult," how hard did you find the task of determining your relative tactical advantage versus your primary opponents during close-in combat?

S12) You never really know where both bandits are at all times!

S83) Three, or less, since the targets did not change their flight elements.

S92) 7 - Hard to gain a picture of what the other aircraft was actually doing.

Question 51) On a scale of 1-10, with 10 being "extremely difficult," how hard did you find the task of determining your relative tactical advantage versus threats other than your primary opponent during close in combat?

S83) Not done against fighters.

Question 54) On a scale from 1-10, with 10 being "extremely difficult," how hard did you find the task of remaining within prescribed airspace while performing close-in combat?

S12) I did not think about it.

S83) Not checked.

S86) Four- (due to the scale).

Question 55) Did you ever "spill out" of prescribed airspace while performing close-in combat?

S86) Maybe.

S91) Don't know - Yes, during defensive evasion.

Question 56) On a scale from 1-10, with 10 being "extremely difficult," how hard did you find the task of maintaining desired maneuver conditions while performing close-in combat?

S12) Better visuals of ground would help.

S92) 9 Poor handling qualities of the flight control system the main reason.

Appendix L. (continued).

Question 57) On a scale of 1-100, what percentage of your available attention do you estimate was allocated to the task of monitoring and controlling the radar while performing close-in combat?

S83) 0% - (CIC modes 20%) not considered as radar control.

Question 61) Were any GCAS alerts experienced during close-in combat? Y/N If so, were you aware of the critical nature of your flight condition at the time? Y/N

S7) Yes, most of time I was aware I was near the ground.

S9) Yes, sometimes.

Question 64) Did you ever lose control of the aircraft during close-in combat? That is, did the aircraft ever do something you did not intend or expect, were you ever below 100 KCAS, did you ever have to recover from a stall or spin, etc.? Y/N If so, explain.

S10) Candidate - Yes, pitched up, lost airspeed, departed. Conventional - N.

S81) Conventional - Yes, only once, but it was a mistake during a missile avoidance.
Candidate - Yes during dogfight and missile avoidance (twice on these two).

S83) Not in CIC.

S85) No, good feedback of airspeed in every cockpit.

S93) Yes, Noise high less than 100 knots - Conventional cockpit.

Question 65) On a scale from 1-10, with 10 being "extremely difficult," how hard did you find the task of determining permissible and optimum weapons launch parameters?

S83) MRM's ; SRM'=6 ; Guns=4

S92) 8 - See earlier comments about dynamic weapons ranges.

Question 68) Did you ever Unintentionally fire a weapon outside indicated permissible launch parameters? Y/N If so, explain.

S7) Candidate - Yes, bombers came up in threat sector. In a hurry to get them launched. All 4 MRM out of range.

S8) Switch error - pulled trigger by mistake. Out of range indication is just absence of in-range indication sometimes fired then noticed absence.

S9) Yes, didn't understand necessity of steering cue.

S11) Yes, I forgot to wait for the "in range indication."

S12) Yes, first intercept not use to displays yet.

S14) Yes. Sometimes launched out of range of the MRM.

S81) Conventional - Yes, a slip between PDT central and trigger.

Appendix L. (continued).

S82) Conventional & Candidate - In close in combat, hostile shown in big on the out the window display - Difficult to get envelope information.

S83) Yes, probably in SRM modes. Not enough time in SRM to look at parameters and not seen obvious information of inside/outside range.

S92) Yes, I was firing MRM's at 25 NM for the sort part of the event.

S93) Yes, misreading range scale in Conventional cockpit.

Question 69) Did you ever INTENTIONALLY fire a weapon outside indicated permissible launch parameters? Y/N If so, explain.

S9) Yes, get bandits jinking.

S12) Yes, anticipated the target would make a turn.

S83 #68 answer can apply to this question; for SRM's were launched without checking those information.

S83) Conventional - location = 4; status = 4; threat = 6. Candidate - locations = 2; status = 3; threat = 2.

S91) Yes, but, only from the Aux console. Last ditch attempt at putting pressure on the cockpit when out of range in a tail chase

Question 75) Were you shot down? Y/N If so, were you aware of the seriousness of the threat at the time Y/N If not explain.

S11) Usually Yes. Once I was shot down by a MRM which was RWR was showing was still 5 miles away.

S14) Yes, during the Candidate cockpit not always in the Conventional cockpit.

S81) Conventional - Yes-yes. Candidate - Yes, the majority yes. But once 2 threats (missiles) were overlapped.

S83) Yes, I probably took too many risks!

S84) Y & N it's hard to estimate the range where a hard break has to be done.

S85) Candidate - Yes. Conventional - No, because 3D sound and all warnings were match together, and RWR was difficult to reach usually.

S92) Yes, lots - mostly I was aware of the threat, but was trying to react within the R.O.E.

S94) Sometimes, yes , sometimes no, workload/laws of physics.

Question 76) Were you always aware of the required response to any threat detected? Y/N If not, explain.

S9) Tough to tell when where to roll w/o visual on missiles.

S12) More training under real conditions to get accustomed to the threats would have helped.

Appendix L. (continued).

S14) Not always in the conventional cockpit.

S81) Conventional - Yes, when in defensive flight.

S86) No, You didn't know how far the missile is and when to fly to maneuver

S92) No- often got RWR before radar contact.

Question 82) On a scale from 1-10, with 10 being "extremely difficult," how hard did you find the task of remaining within prescribed airspace while performing an egress?

S12) I really don't know that this was a requirement.

Question 83) Did you ever "spill out" of prescribed airspace during an egress?

S14) Maybe, I don't know when I was running from a missile. I didn't care about my flight path.
Normal egress was easy without a threat on my tail.

S84) Yes, on Conventional aircraft.

S91) Yes, evading a missile.

Question 84) On a scale of 1-100, what percentage of you available attention do you estimate was allocated to the task of visually searching for targets while performing an egress?

S91) 0 - They were always behind me on the few occasion performed on egress.

**Question 85) Did you experience any instances of loss of spatial awareness while performing an egress? Y/N If so, would you categorize this event a minor, moderate or serious?
Min/Mod/Ser**

S83) Yes, while performing a defensive maneuver during egress - serious.

Question 86) Were any GCAS alerts experienced during egress? Y/N If so, were you aware of the critical nature of your flight condition at the time? Y/N

S9) Generally GCAS came on during defensive maneuvering.

S83) Yes, during defensive maneuvers. No, at the first time then yes.

Question 91) Did you ever hit the ground during a mission? Y/N If so, during what mission phase? CAP, Intercept, Maneuver (within 3 NM of hostile airspace, Egress. If so, were you aware of the critical situation prior to impact? Y/N

S10) Maneuver (within 3 NM of hostile aircraft).
Yes, a split second before I crashed I knew it was too late.

S84) The Scale shifting isn't useful. Memory time linked with the frame of the scan: is it a good idea?

S85) Yes, with the Conventional during close in egress.

S93) Yes, Maneuver. Not, normally. Yes, on one occasion I had GCAS but did not perform recovery correctly.

ACRONYMS AND ABBREVIATIONS

AAA	Anti-Aircraft Artillery
AAM	Air-to-Air Missile
ADI	Attitude Display Indicator
AGL	Above Ground Level Altitude
AMRAAM	Advanced Medium Range Air-to-Air Missile
AOA	Angle of Attack
ARMs	Anti-Radiation Missiles
ASE	Allowable Steering Error
ATHS	Automatic Targeting Hand-Off System
BDA	Battle Damage Assessment
BST	Boresight
BVR	Beyond-Visual-Range
CAP	Combat Air Patrol
CAS	Close Air Support
CDI	Course Deviation Indicator
CIC	Close In Combat
DCA	Defensive Counter-Air
deg.	Degree
ECM	Electronic Countermeasures
EO	Electro-Optics
FITE	Fusion Interfaces for Tactical Environments Laboratory
FLIR	Forward-Looking Infrared
FOR	Field of Regard
FOV	Field Of View
FPM	Feet Per Minute
ft.	feet
GCAS	Ground Collision Avoidance System
GPS	Global Positioning System
HDD	Head-Down Display
HMD	Helmet Mounted Display
HOTAS	Hands On Throttle And Stick
HSI	Horizontal Situation Indicator
HUD	Head-Up Display
IAMs	Inertially Aided Munitions
ID	Identification
INS	Inertial Navigation System
lps	Initial Points
IR	Infrared
IRST	Infrared Search and Track
ISAR	Inverse Synthetic Aperture Radar
JTIDS	Joint Tactical Information Data System
KCAS	Knots Calibrated Air Speed
KIAS	Knots Indicated Air Speed
KTAS	Knots True Air Speed
LADAR	Laser Radar
LANTIRN	Low Altitude Navigation and Targeting InfraRed for Night
lbs.	pounds
LCD	Liquid Crystal Display
LCOS	Lead Computing Optical Sight
LDGP	Low Drag General Purpose
LGBs	Laser-Guided Bombs

Appendix M. (continued)

LO	Low-Observability
LOS	Line Of Sight
LPI	Low Probability of Intercept
LRFs	Laser Range Finders
Mhz	Mega hertz
MMW	Millimeter-Wave-Radar
MRF	Multi-Role Fighter
MRM	Medium Range Missile
MSL	Mean Sea Level
MWS	Missile Warning Systems
NCTR	Non-Cooperative Target Recognition
NM	Nautical Mile
OTW	Out-The-Window display
PD	Pulse-Doppler
PDT	Primary Designated Target
POM	Plane Of Maneuver
PRF	Pulse-Repetition Frequency
RWR	Radar Warning Receiver
RWS	Range-While-Search
SA	Situation Awareness
SAM	Surface-to-Air Missile
SAR	Synthetic Aperture Radar
SLAM	Stand-Off Land Attack Missile
S.D.	Standard Deviation
SRM	Short Range Missile
SSI	Systems Status Indicator
SSL	Sleable Scan Lock
STT	Single Target Track
TAA	Target Aspect Angle
TACAN	Tactical Air Navigation
TAS	True Air Speed
TD	Target Designator
TDI	Target Direction Indicator
TF/TA	Terrain-Following/Terrain Avoidance
TID	Target Identification System
TTA	Time To Active
TTG	Time To Go
TWS	Track-While-Scan
VSD	Vertical Situation Display
VSL	Vertical Scan Lock
VTOL	Vertical Takeoff And Landing
WVR	Within-Visual-Range